creative commons

COMMONS DEED

저작자표시-비영리-변경금지 2.0 대한민국

이용자는 아래의 조건을 따르는 경우에 한하여 자유롭게

- 이 저작물을 복제, 배포, 전송, 전시, 공연 및 방송할 수 있습니다.

다음과 같은 조건을 따라야 합니다:

저작자표시. 귀하는 원저작자를 표시하여야 합니다.

비영리. 귀하는 이 저작물을 영리 목적으로 이용할 수 없습니다.

변경금지. 귀하는 이 저작물을 개작, 변형 또는 가공할 수 없습니다.

- 귀하는, 이 저작물의 재이용이나 배포의 경우, 이 저작물에 적용된 이용허락조건을 명확하게 나타내어야 합니다.
- 저작권자로부터 별도의 허가를 받으면 이러한 조건들은 적용되지 않습니다.

저작권법에 따른 이용자의 권리는 위의 내용에 의하여 영향을 받지 않습니다.

이것은 이용허락규약(Legal Code)을 이해하기 쉽게 요약한 것입니다.

Disclaimer

dCollection

농학박사학위논문

A Forecast Model for Bacterial Grain Rot of Rice and Its Implementation in the National Crop Pest Management System

세균벼알마름병 예측 모형과 국가농작물병해충관리시스템 적용

2016년 2월

서울대학교 대학원

농생명공학부 식물미생물학전공

이 용 환

A FORECAST MODEL FOR BACTERIAL GRAIN ROT OF RICE AND ITS IMPLEMENTATION IN THE NATIONAL CROP PEST MANAGEMENT SYSTEM

A dissertation submitted in partial fulfilment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

to the Faculty of
Department of Agricultural Biotechnology

at

SEOUL NATIONAL UNIVERSITY

by

YONG HWAN LEE

FEBURARY, 2016

농학박사학위논문

세균벼알마름병 예측 모형과 국가농작물병해충관리시스템 적용

지도교수 박 은 우

이 논문을 농학박사학위논문으로 제출함

2016년 2월

서울대학교 대학원

농생명공학부 식물미생물학전공

이 용 환

이용환의 박사학위논문을 인준함

2016년 2월

위 원 장 이 인 원 (인)

부위원장 박 은 우 (인)

위 원 황 인 규 (인)

위 원 김 영 호 (인)

위 원 윤 성 철 (인)

A THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

A FORECAST MODEL FOR BACTERIAL GRAIN ROT OF RICE AND ITS IMPLEMENTATION IN THE NATIONAL CROP PEST MANAGEMENT SYSTEM

UNDER THE DIRECTION OF DR. EUN WOO PARK

SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF SEOUL NATIONAL UNIVERSITY

BY

YONG HWAN LEE

MAJOR IN PLANT MICROBIOLOGY
DEPARTMENT OF AGRICULTURAL BIOTECHNOLOGY

FEBURARY 2016

APPROVED AS A QUALIFIED THESIS OF YONG HWAN LEE
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
BY THE COMMITTEE MEMBERS

CHAIRMAN Yin-Won Lee

VICE CHAIRMAN Eun Woo Park

MEMBER Hwang Ingyu

MEMBER Yong Ho Kim

MEMBER Sungchul Yun

A forecast model for bacterial grain rot of rice and its implementation in the National Crop Pest Management System

Yong Hwan Lee

ABSTRACT

Bacterial grain rot (BGR) of rice, which is caused by *Burkholderia glumae*, occurs worldwide and is a constraint on rice production by infecting spikelets of panicles. Seedling symptoms of *B. glumae* infection include brown, water-soaked soft rot of the leaf sheaths. Infected grains are shrunken and pale-green, later becoming dirty-yellow to brow and very dry. Severe infections could result in substantial yield loss. Previous studies on population dynamics on rice plants showed that colonization of leaf sheaths by the pathogen plays an important role in primary infection. Disease incidence of BGR varies every year depending on weather conditions in Korea. Currently, no resistant cultivars have been reported yet. The major strategy to control the disease is one or two chemical sprays around the heading stage of rice plants. However, chemical sprays are often made by rice growers even if weather conditions are not favorable enough for epidemic development of the disease. The present study was conducted

(1) to determine a quantitative measure of environmental conduciveness to epidemic development of BGR; (2) to develop a forecast model based on the conduciveness of weather conditions to decide whether to spray chemicals during the heading stage of rice plants; and (3) to implement the BGR forecast model in the National Crop Pest Management System (NCPMS) of the Rural Development Administration. The disease forecast model, which was named 'BGRcast', determined daily conduciveness of weather conditions to epidemic development of BGR and forecasts risk of BGR development. All data that were used to develop and validate the BGRcast model were collected from field observations on disease incidence at Naju, Korea during 1998-2004 and 2010. In this study, we have proposed the environmental conduciveness as a measure of conduciveness of weather conditions for population growth of *B. glumae* and panicle infection by the bacteria in the field. The BGRcast calculated daily environmental conduciveness, C_i , based on daily minimum temperature and daily average relative humidity. With regard to the developmental stages of rice plants, the epidemic development of BGR was divided into three phases, i.e., survival, inoculum build-up and infection phases. Daily average of C_i were calculated for the inoculum build-up phase (C_{inc}) and the infection phase (C_{inf}). The C_{inc} and C_{inf} were considered environmental conduciveness for the periods of

inoculum build-up in association with rice plants and panicle infection during the heading stage. The disease forecast model was able to forecast correctly actual occurrence of BGR at the probability of 71.4% and its false alarm ratio was 47.6%. With the thresholds of $C_{inc} = 0.3$ and $C_{inf} = 0.5$, the model was able to provide advisories that could be used to make decisions on whether to spray bactericide at the pre- and post-heading stage. It was concluded that BGRcast could be used in practice by rice growers to improve effectiveness of conventional spray programs to control BGR. The NCPMS is the nation-wide disease and insect pest management system for agricultural crops. NCPMS is composed of three main systems; monitoring, forecasting and diagnosis of diseases and insect pests. Currently, BGRcast is being used in NCPMS to support rice growers who are keen to spray chemicals only when infection risk of *B. glumae* is high enough to cause significant yield loss. The forecast information is delivered to registered users via short message service (SMS) automatically at 7 AM every day. The number of registered users has increased from 1,136 users in 2011 to 4,013 in 2014.

Keywords: BGRcast, chemical control, environmental conduciveness, National Crop Pest Management System (NCPMS), rice bacterial grain

rot, weather-driven disease forecast model, web-based forecasting system

Student Number: 2005-30373

CONTENTS

Page

LIST OF TABLES

CHAPTER 1. BGRcast: A disease forecast model to support decision-making for chemical sprays to control bacterial grain rot of rice

Page

CHAPTER 2. Implementation of BGRcast model in the National Crop Pest Management system

Page

LIST OF FIGURES

CHAPTER 2. Implementation of BGRcast model in the National Crop Pest Management system

Page

CHAPTER 1

BGRcast: A Disease Forecast Model to Support Decision-making for Chemical Sprays to Control Bacterial Grain Rot of Rice

ABSTRACT

A disease forecast model for bacterial grain rot (BGR) of rice, which is caused by *Burkholderia glumae*, was developed in this study. The model, which was named 'BGRcast', determined daily conduciveness of weather conditions to epidemic development of BGR and forecasts risk of BGR development. All data that were used to develop and validate the BGRcast model were collected from field observations on disease incidence at Naju, Korea during 1998-2004 and 2010. In this study, we have proposed the environmental conduciveness as a measure of conduciveness of weather conditions for population growth of *B. glumae* and panicle infection by the bacteria in the field. The BGRcast calculated daily environmental conduciveness, C_i, based on daily minimum temperature and daily average relative humidity. With regard to the developmental stages of rice plants, the epidemic development of BGR was divided into three phases, i.e., survival, inoculum build-up and infection phases. Daily average of C_i were calculated for the inoculum build-up phase (C_{inc}) and the infection phase (C_{inf}). The C_{inc} and C_{inf} were considered environmental conduciveness for the periods of inoculum build-up in association with rice plants and panicle infection during the heading stage. The disease forecast model was able to forecast correctly actual occurrence of BGR at the probability of 71.4% and its false alarm ratio was 47.6%. With the thresholds of

$C_{inc} = 0.3$ and $C_{inf} = 0.5$, the model was able to provide advisories that could be used to make decisions on whether to spray bactericide at the pre- and post-heading stage. It was concluded that BGRcast could be used in practice by rice growers to improve effectiveness of conventional spray programs to control BGR.

Keywords: rice bacterial grain rot, BGRcast, weather-driven disease forecast model, environmental conduciveness, chemical control

INTRODUCTION

Bacterial grain rot (BGR) of rice, which is caused by *Burkholderia glumae* (Kurita and Tabei 1967; Urakami et al., 1994), is one of the major disease problems in global rice production (Ham et al., 2010). *B. glumae* has been reported as a rice pathogen present in many rice-growing countries worldwide (Jeong et al., 2003; Kim et al., 2010; Luo et al., 2007; Trung et al., 1993; Nandakumar et al., 2009; Shahjahan et al., 2000; Andrea and Fernando, 2014; Riera-Ruiz et al., 2014) since it was first described in Japan (Goto and Ohata, 1956). Symptoms of BGR include grain rot (also referred to as panicle blight), seedling rot and sheath rot. Diseased panicles usually have spikelets blighted with rotten grains. Upright panicles with brown color are typically found in severely infected fields (Ham et al., 2010). This symptom causes serious yield losses (Cha et al., 2001; Tsushima et al., 1995b). Yield loss caused by BGR were up to 40% in 1995 and 1998 in Louisiana (Nandakumar et al., 2009; Shahjahan et al., 2000) and 75% loss in grain yield has been reported in Vietnam (Trung et al., 1993).

Bacterial seedling rot can also be caused by rapid increase of *B. glumae* population in the epidermis of plumules (Hikichi, 1993a; Hikichi et al., 1995). *B. glumae* were found in and on the upper and lower epidermis (Hikichi et al., 1993) and could survive on the leaf sheath of upper leaves and the flag leaf without showing rot symptoms

(Hikichi, 1993c). It then invades flowering spikelets, multiplies rapidly and finally causes grain rot (Hikichi et al., 1998; Hikichi et al., 1994).

Outbreak of the BGR epidemics varied depending on weather conditions during the heading period of rice (Lee et al., 2010). It generally occurred under conditions of prolonged high temperatures and frequent rainfall during the heading and flowering periods of rice (Cha et al., 2001; Tsushima et al., 1995b). The spikelets were most susceptible on the day of flowering and the bacteria favored humid conditions of over 95% relative humidity for 24 hours at flowering (Tsushima et al., 1995a). Yokoyama and Okuhara (1987) noted that BGR developed when minimum daily temperature was ≥23 ℃ and moderate rainfall (< 30mm/day) occurred during the heading stage of rice.

Use of pathogen-free seeds, seed treatment and foliar sprays of bactericides such as oxolinic acid and kasugamycin are the main tactics to control BGR (Azegami et al., 1987; Hikichi, 1993a; Hikichi, 1993b; Hikichi, et al., 1994; Hikichi et al., 1995; Isogawa et al., 1989). Especially the foliar sprays were recommended two times, i.e. before and after the heading stage of rice plants. Also, recently rice health management programs often recommend the one-shot application of granular formulations of disease resistance-inducing chemicals, such as tiadinil, orysastrobin and isotianil, to rice seedlings in the nursery boxes to control multiple diseases such as leaf sheath blight, rice blast, bacterial leaf blight and BGR (Takashi and Hideo, 2013). In the rice health management programs, no further chemical applications before and after the heading stage of rice were advised to control diseases on rice panicles. The changes in chemical control strategy in the rice health management programs and the yearly variations of BGR incidence caused difficulty to rice growers protecting panicles from BGR. Consequently disease forecasts for possible risks of BGR would help rice growers decide whether to spray bacteriocide before and after the heading stage for better management of rice health. Besides, it may help save disease control cost by reducing the use of expensive chemicals like oxolinic acid.

As an effort to develop disease forecast models for BGR, Tsushima et al. (1996) reported that the detection frequency of the pathogen on flag leaf sheaths was significantly correlated with disease incidence on panicles a week after the heading time. They found that the bacterial population on flag leaf sheaths was important in primary infection of the disease. However, application of the bacterial population model by Tsushima et al. (1996) is not practical due to low efficiency of dilution plate method in detecting naturally occurring populations of the bacteria in the field.

The weather-driven models developed by Lee et al. (2004) were linear regression models with various weather factors as predictor variables. They selected a multiple regression model with six predictor variables including minimum and average temperatures and relative humidity, number of rainy days and average wind speed during 7 days from 3 days before to 3 days after the heading date. The coefficient of determination (R^2) of the model was 0.824, indicating that 82.4% of the variation in disease incidence was accounted for by the six predictor variables. However, the multiple regression model has overestimated BGR development in 1999 and 2001 when no disease occurred (unpublished data).

In this study, we have established the following hypotheses regarding conditions for epidemic development of BGR in rice paddy fields: (1) *B. glumae* needs to attain a certain population size in upper leaf sheaths of rice plants prior to the heading stage, and (2) weather conditions need to be favorable for the bacterial infection during the heading stage of rice plants. Based on the hypothesis, , a disease forecast model for BGR (referred to as BGRcast hereafter) was developed to determine conduciveness of weather conditions for population growth of *B. glumae* in association with rice plants and panicle infection by the bacteria during the heading stage of rice plants. The BGRcast was also evaluated regarding its capacity to support decision-making for bactericide sprays at the pre- and post-heading stage in the field. In this study, we have analyzed disease and weather data that were obtained from multi-year field experiments in 1998-2004 and 2010. Of the data sets, the same data from 1998 were used in the previous study to develop linear regression models (Lee et al., 2004).

MATERIALS AND METHODS

Ⅰ. Field plot.

Disease incidence of BGR was obtained from an experimental rice paddy field where local performance tests were conducted to select rice cultivars suitable for the Jeonnam Province in 1998-2004 and 2010. In order to evaluate agronomic performance each year, 11-29 rice cultivars were grown at the experimental paddy field located at the Jeonnam Agricultural Research and Extension Services (JARES) in Naju, Korea. Rice seeds disinfected by prochloraz EC (Hankooksamgong Co., Ltd., Korea) were sown and raised on the protected semi-irrigated rice nursery for 30 days. Three to five rice seedlings of 30-days old were transplanted per hill on 30 May and 15 June each year. The experimental paddy field was divided into the early and the late transplanting plots. On each plot, rice cultivars were planted in a randomized block design with 3 replications. Each experimental unit consisted of 6 rows 30 cm apart and 90 hills per row at the between-hill space of 14 cm. Consequently the total of 540 hills composed an experimental unit for each rice cultivar. Fungicides and insecticides were sprayed following the calendar-based conventional spray program. However, no bactericides were applied for this study.

Ⅱ. Disease and rice growth assessment.

Disease incidence of BGR was measured in terms of the percentage of infected panicles per hill at three weeks after the heading date of rice plants, which was determined when approximately 40% of panicles emerged. Disease assessment was made by counting the number of diseased and healthy panicles in a hill. For the sake of efficiency of disease assessment, only 100 hills per plot were sampled at random when more than 30% panicles were diseased. For those plots with less than 30% panicles diseased, all 540 hills per plot were examined. Disease incidence of a plot was determined by dividing the number of diseased panicles by the total number of panicles of the hills that were examined in the plot. Disease incidence data obtained from three replications for each cutivar and transplanting date were pooled together prior to data analyses. Since disease incidence data showed systematic increase in variation over time, disease incidence data were log-transformed by taking $\ln(\%\,\text{disease incidence} + 1)$ before statistical analysis.

Plant growth of each rice cultivar was monitored every day to determine the developmental dates of rice such as the date of first panicle emergence and the heading date at which approximately 40% panicles emerged.

Ⅲ. Weather and disease data.

Daily weather data on minimum and maximum temperature, average relative humidity and rainfall were obtained from the synoptic weather data provided by the Gwangju Regional Meteorological Administration, Korea. The disease incidence, rice plant development and weather data from 1998-2000 were used to develop a disease forecast model for BGR. Validation of the disease forecast model was performed based on the data from 2001-2004 and 2010.

Ⅳ. Three phases of epidemic development of BGR.

Considering epidemiology of *B. glumae*, epidemic development of BGR was divided into three phases with regard to the developmental stages of rice plants (Fig. 1). The lag phase starts from the transplanting date and continues until weather conditions become favorable for rapid growth of the bacterial population. The inoculum build-up phase is the period that the bacterial population is able to increase significantly to colonize the leaf sheaths of upper leaves and the flag leaf. It is assumed

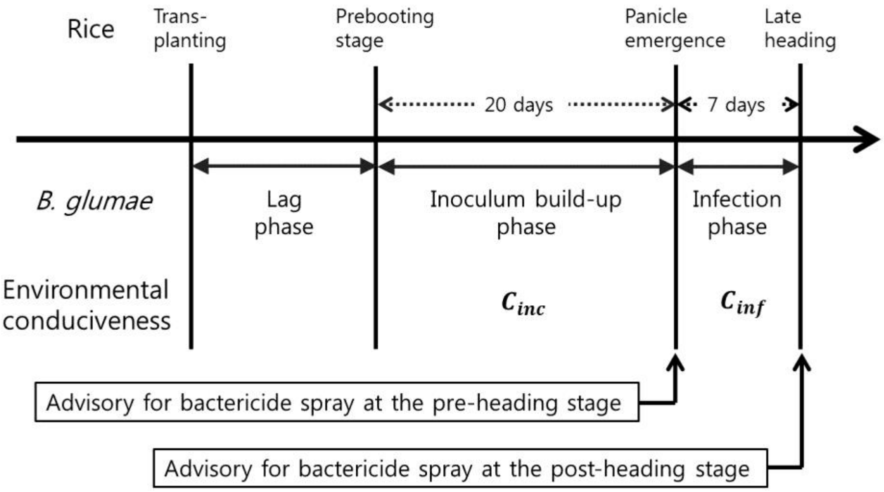


Fig. 1. Three phases of epidemic development of BGR with regard to the developmental stages of rice plants. The duration of inoculum build-up phase was determined empirically to be 20 days prior to the first panicle emergence. The infection phase was assumed to be 7 days from the first panicle emergence, during which the majority of panicles emerged in the field. Time for advisory was indicated to support decision-making on bactericide sprays.

that this period starts during the prebooting stage of rice plants and ends at the first panicle emergence when spikelets on panicles become available for infection by *B. glumae*. The infection phase is assumed to be 7 days of the heading stage from 3 days prior to the heading date to 3 days after the heading date. It is known that the majority of panicles emerge during this period (Lee, 2010). Panicle infection occurs during the infection phase and subsequently developed grain rot symptoms.

Since bacterial growth rate is affected by environmental conditions, the transition time from lag phase to inoculum build-up phase would vary from year to year. In this study, an empirical approach was made to delineate the two phases by examining statistical correlations between conduciveness of weather conditions for BGR development during the infection phase and disease development in 1998-2004 and 2010. The correlation coefficients obtained by changing duration of the inoculum build-up phase were compared to determine the most appropriate date for delineating the lag and inoculum build-up phases. For this analysis, the duration of inoculum build-up phase was counted backward from the date of first panicle emergence that was observed for individual rice cultivars in the experimental field each year.

Ⅴ. Daily conduciveness model.

Conduciveness of weather conditions to epidemic development of BGR was evaluated using daily minimum temperature and average relative humidity. The daily weather data in 1998-2000 were used for the model development. The daily conduciveness, which is subjected to relative humidity conditions, was determined by the BGRcast model as follows:

If $RH_i \geq RH_{base}$, then $C_i = \mathrm{Max}(0, (Tn_i - Tn_{base}))$

Else $C_i = 0$

where Tn_i and RH_i are daily minimum temperature and average relative humidity on day i, respectively; and C_i is the daily conduciveness of weather conditions on day i. The base temperature (Tn_{base}) and relative humidity (RH_{base}) in the BGRcast model were determined empirically using the disease incidence and weather data from 1998-2000. The C_i is determined every day starting from the transplanting date until the end of heading stage of rice plants.

The average of C_i was calculated for the inoculum build-up and infection phases of BGR development by:

$$C = \frac{1}{n}\sum_{1}^{n} C_i$$

where C is the daily average of C_i for the period of each phase of

BGR development, and n is the number of days for the period. For the inoculum build-up and infection phases, C will be denoted as C_{inc}, and C_{inf}, respectively. In order to determine n for C_{inc}, 10, 15, 20, 25 and 30 days prior to the date of first panicle emergence were evaluated empirically based on the correlation coefficients between disease incidence and C_{inf} using the data from 1998-2004 and 2010. The n for C_{inf} is 7 days from 3 days prior to the heading date to 3 days after the heading date as described above in the definition of infection phase. Since C_{inc} indicates conduciveness of weather conditions for inoculum build-up of *B. glumae*, it is assumed that no inoculum is available for panicle infection if $C_{inc} = 0$. Consequently, C_{inf} is calculated only if $C_{inc} > 0$. Otherwise, C_{inf} is assigned zero even if weather conditions during the infection phase are conducive to panicle infection by the bacteria.

VI. Thresholds of C_{inc}, and C_{inf}.

Thresholds of C_{inc} and C_{inf} that can be used as criteria for deciding whether to spray bactericides were determined based on their relationship with disease incidence in 1998-2000. Since two sprays of bactericides at the pre- and post-heading period of rice plants are commonly made by rice growers in Korea, C_{inc} and C_{inf} can be used to determine whether to spray bactericides at the pre- and post-heading stage, respectively.

Ⅶ. Model validation and application.

The BGRcast model was tested for its capacity to forecast risk of infection by *B. glumae* using disease and weather data from 2001-2004 and 2010. Temporal changes of C_i, C_{inc} and C_{inf} were examined for each year and validation of the BGRcast model was performed in three ways: (1) The relationship between C_{inf} and log-transformed disease incidence using 226 data sets from the field experiments was analyzed to evaluate the capacity of C_{inf} in describing variations of BGR incidence under different weather conditions ; (2) the observed disease incidence in 2001-2004 and 2010 was compared with those estimated by the regression equation describing the relationship between disease incidence and C_{inf} in 1998-2000; and (3) the two-way contingency table analysis (Sokal and Rohlf, 1973) was conducted to evaluate accuracy of BGR forecast by the BGRcast model. A contingency table was created for two variables, method (observation and forecast) and output (disease and no disease). In the two-way contingency table analysis, three categorical measures of accuracy for disease forecast were calculated. The probability of detection (POD) is the percent of disease development that are correctly forecasted, and the false alarm ratio (FAR) is a measure of the failure of the BGRcast model to exclude no disease cases. The bias score (or ‘frequency bias’) is a measure of the extent to which one response is more probable than another (Jolliffe and Stephenson, 2012). In this study, the bias score was the ratio of positive forecast frequency to observed frequency of disease occurrence, so that it measured how frequently the BGRcast model forecasted BGR as compared to the observed occurrence of BGR.

The BGRcast model was applied to the data from different rice cultivars in 2001 and 2010 to evaluate its effectiveness in determining whether to spray bactericides at the pre- and post-heading stage of rice plants. In order to examine responses of C_{inc} and C_{inf} to different heading dates of rice plants, rice cultivars with different heading dates at late July and early, mid and late August were selected and recommendations for the bactericide sprays at the pre- and post-heading period were determined based on C_{inc} and C_{inf}, respectively. Effectiveness of the forecast model was discussed by taking disease incidence into consideration with reference to the disease forecast.

RESULTS

Ⅰ. Heading dates and disease incidence.

Table 1 shows rice heading dates and disease incidence of BGR on 11 rice cultivars when seedlings were transplanted on 30 May and 15 June in 1998-2000. It was commonly noticed in the field that panicle emergence started approximately 3 days before the heading date. The rice cultivars were grouped by the maturity types. The heading date of a cultivar varied depending upon year and transplanting date, indicating that weather conditions after transplanting affected the heading dates of rice cultivars. The late transplanting by 16 days resulted in late headings by 6-9 days in 1998, 11-14 days in 1999, and 3-5 days in 2000. Rice cultivars within a same maturity type showed similar heading dates as compared with the differences in heading dates between different maturity types.

Disease incidence varied among three replications for each cultivar and transplanting date due to obvious spatial variations in disease incidence over the experimental field. In order to negate the effect of spatial variations in the data analyses, BGR incidence data obtained from three replications were pooled together prior to the analyses. Disease incidence also varied depending upon years, transplanting dates,

Table 1. Rice heading date and disease incidence of BGR on 11 rice cultivars when seedlings were transplanted on 30 May and 15 June in 1998 - 2000

Maturity Types	Rice Cultivars	1998				1999				2000			
		30 May		15 Jun		30 May		15 Jun		30 May		15 Jun	
		Heading date[a]	Diseased panicles (%)	Heading date	Diseased panicles (%)	Heading date	Diseased panicles (%)	Heading date	Diseased panicles (%)	Heading date	Diseased panicles (%)	Heading date	Diseased panicles (%)
Early	Samcheon	2 Aug	18.3	11 Aug	69.2	27 July	0.0	10Aug	0.0	-[b]	-	-	-
	Odae	3 Aug	37.8	12 Aug	53.9	29 July	0.0	11 Aug	0.0	-	-	-	-
Middle	Ganchek	8 Aug	21.7	17 Aug	9.5	4 Aug	0.0	15 Aug	0.0	10 Aug	0.3	14 Aug	1.1
	Shinseonchal	10 Aug	12.8	19 Aug	6.3	6 Aug	0.0	18 Aug	0.0	11 Aug	0.3	14 Aug	0.9
Middle to late	Aryanghyangchal	14 Aug	37.6	22 Aug	0.0	14 Aug	0.0	26 Aug	0.0		-	-	-
	Keumnam	16 Aug	9.0	24 Aug	0.0	14 Aug	0.0	26 Aug	0.0	13 Aug	2.8	17 Aug	6.1
	Yangjo	16 Aug	11.0	24 Aug	0.0	10 Aug	0.0	23 Aug	0.0	13 Aug	2.0	18 Aug	4.8
	Dongan	17 Aug	20.1	24 Aug	0.0	13 Aug	0.0	25 Aug	0.0	15 Aug	2.0	18 Aug	0.9
	Mankeum	17 Aug	3.9	24 Aug	0.0	12 Aug	0.0	25 Aug	0.0	-	-	-	-
	Kyehwa	17 Aug	3.8	25 Aug	0.0	14 Aug	0.0	27 Aug	0.0	-	-	-	-
	Daesan	19 Aug	5.6	25 Aug	0.0	14 Aug	0.0	26 Aug	0.0	-	-	-	-

[a] Date when 40% of panicles were emerged, [b] No data available.

and rice cultivars. Severe epidemic of BGR occurred in 1998 with disease incidence ranging 0-69.2%, whereas there was no disease observed in 1999. Disease incidence in 2000 ranged 0.3-6.1% on five rice cultivars. In 1998, rice cultivars Samcheon and Odae, which belonged to the early maturity type, were diseased more severely when transplanted at 15 June than at 30 May. On the contrary, the other rice cultivars that belonged to the middle and middle-to-late maturity types showed higher disease incidence when transplanted at 30 May than at 15 June. When compared between transplanting dates for each rice cultivar, disease incidence in 1998 was higher when panicle heading occurred on mid August (8-14 August) than on early (2-3 August) or late (16-25 August).

Summary of data from the performance trials conducted in 2001-2004 and 2010 are presented in Table 2. Different heading dates were induced by transplanting at different dates. The number of diseased cultivars and disease incidence varied depending on years and transplanting dates. Weather conditions were favorable for *B. glumae* only in 2010 especially when transplanted early.

Table 2. Summary of collected data from the experimental field plot for local performance tests on rice cultivars in 2001-2004 and 2010

Year	No. of cultivars	Transplanting date							
		30 May				15 June			
		No. of diseased cultivars	Heading date	Disease incidence (%)		No. of diseased cultivars	Heading date	Disease incidence (%)	
				Mean±Sd	Range			Mean±Sd	Range
2001	29	0	27 Jul-16 Aug	0	0	0	9 Aug-26 Aug	0	0
2002	13	6	29 Jul-15 Aug	0.20±0.30	0 - 0.8	0	11 Aug-25 Aug	0	0
2003	23	0	3 Aug-18 Aug	0	0	0	14 Aug-25 Aug	0	0
2004	25	10	26 Jul-13 Aug	0.06±0.09	0 -0.24	2	8 Aug-24 Aug	0.02±0.07	0 -0.33
2010	23	23	26 Jul-17 Aug	9.70±17.16	0.002 - 77.78	22	8 Aug-25 Aug	0.72±0.56	0 -1.89

Ⅱ. Base temperature and relative humidity.

Using the disease incidence and daily minimum temperature and mean relative humidity in 1998-2000, the scatter diagrams were plotted in Fig. 2. It was noticed in the scatter diagrams that no disease was observed when daily minimum temperature was lower than 22℃ or when daily mean relative humidity was lower than 80%. Based on this observation, the base temperature (Tn_{base}) and relative humidity (RH_{base}) were determined to be 22℃ and 80%, respectively, in the BGRcast model. Consequently, the BGRcast model becomes:

If $RH_i \geq 80\%$, then $C_i = \text{Max}(0, (Tn_i - 22))$

Else $C_i = 0$

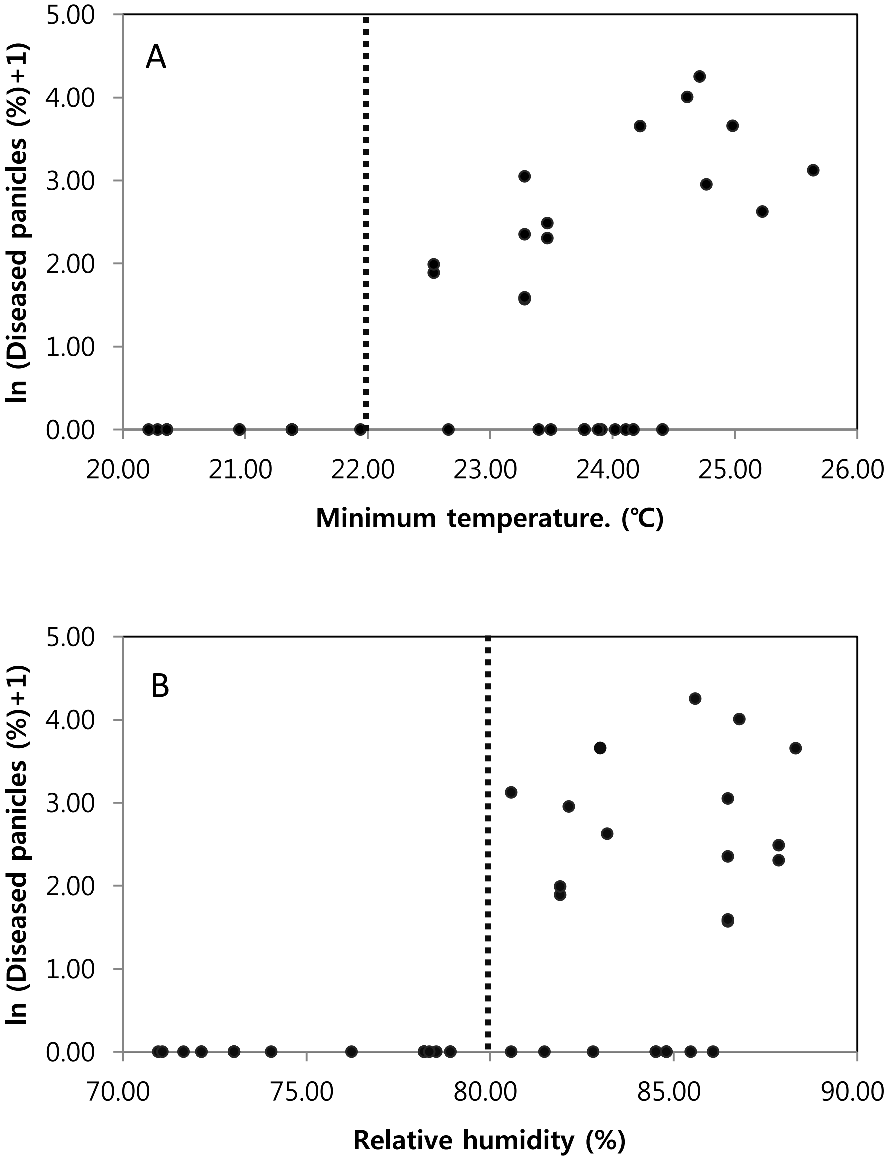


Fig. 2. Disease incidences of BGR in 1998-2000 corresponding to the average of daily minimum temperature (A) and mean relative humidity (B) during the 7 days from the date of first panicle emergence in 1998-2000.

Ⅲ. Delineation between the lag and inoculum build-up phases.

Using all data from 1998-2004 and 2010, C_{inc} and C_{inf} were calculated for 10, 15, 20, 25 and 30 days prior to the date of first panicle emergence. In this calculation, if $C_{inc} = 0$, then C_{inf} was assigned 0 even if the weather conditions during the heading stage were favorable for panicle infection by *B. glumae*. The correlation coefficients between C_{inf} and BGR incidence were plotted against the number of days prior to the date of first panicle emergence (Fig. 3). All correlation coefficients were statistically significant ($p \leq 0.05$) and it was highest for 20 days. Based on this result, C_{inc}, which is the average daily conduciveness during the inoculum build-up phase, was calculated for 20 days prior to the date of first panicle emergence.

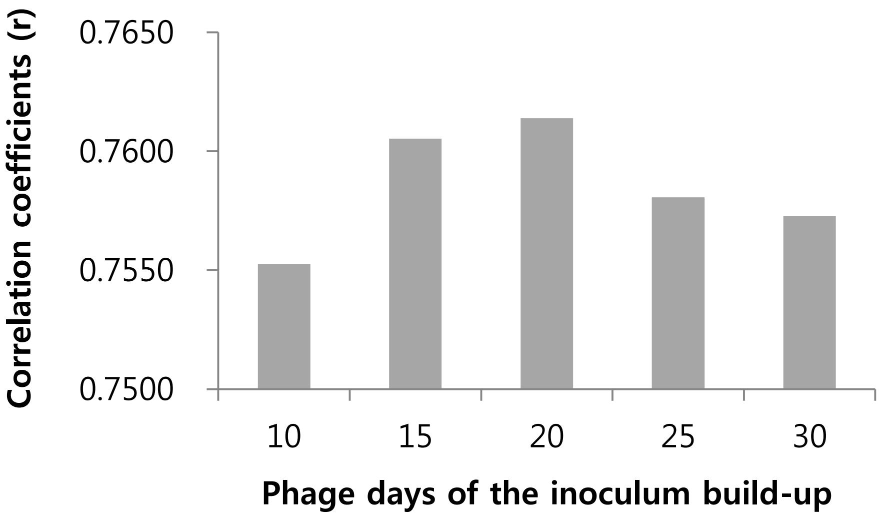


Fig 3. Correlation coefficients between log-transformed disease incidence and C_{inf} in 1998-2004 and 2010. The C_{inf} was calculated with regard to the corresponding C_{inc} for 10, 15, 20, 25 and 30 days prior to the date of first panicle emergence.

Ⅳ. Environmental conduciveness to BGR epidemic.

Environmental conduciveness of weather conditions to epidemic development of BGR was calculated for 1998-2000 using the BGRcast model (Fig. 4). The daily conduciveness, C_i, showed clear difference among the three years in weather conditions for BGR development. The C_{inc}, which is the moving average of C_i for the past 20 days, indicated yearly differences in conduciveness of weather conditons for inoculum build-up prior to the first panicle emergence. In 1998, weather conditions were favorable for inoculum build-up of the bacteria from 27 June until the end of August. In 1999, however, C_{inc} remained zero until 22 July, indicating that weather conditions were not conducive to inoculum build-up until mid to late July. In 2000, C_{inc} were higher than zero from 1 July to the end of August, suggesting that the bacterial population in association with rice plants was probably able to increase at a minimal level prior to panicle emergence of rice plants.

Conduciveness of weather conditions to panicle infection by *B. glumae* during the heading stage of rice plants was plotted in Fig. 4. The C_{inf} is the average of C_i for 7 days from 3 days prior to the heading date to 3 days after the heading date. It was observed that the

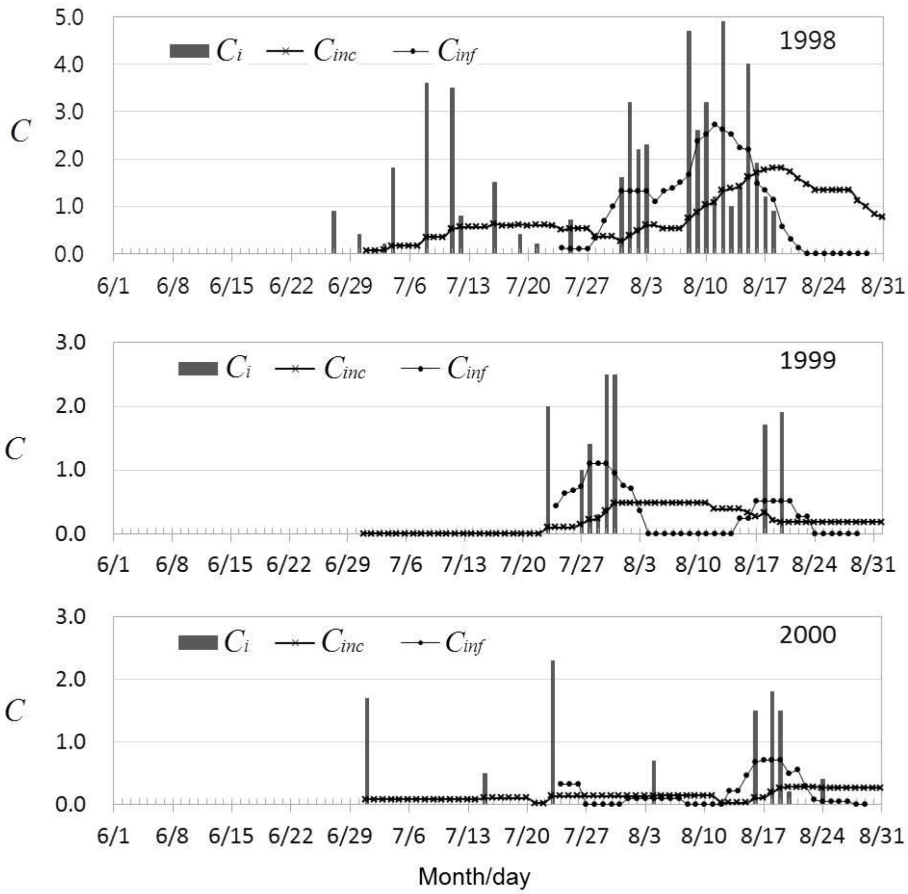


Fig. 4. Temporal change of C_i, C_{inf}, and C_{inc} calculated by the BGRcast model using weather data from 1998-2000.

more than 80% of panicles were emerged during the 7 days. In 1998, C_{inf} indicated that weather conditions were highly conducive to panicle infection by the bacteria throughout the heading stage of rice plants. The C_{inf} became zero on 22 August and afterward. In 1999, C_{inf} was zero prior to 21 July and during 4-14 August, and weather conditions were conducive to panicle infection for short periods during 23 July-3 August and 15-23 August. The C_{inf} was down to zero after 24 August. In 2000, weather conditions during late July and August were slightly conducive to panicle infection except for the short periods of 27-31 July and 8-12 August. The C_{inf} remained zero from 28 August.

In order to evaluate epidemiological significance of the environmental conduciveness that was measured by C_{inf}, a regression analysis was conducted between C_{inf} and log-transformed disease incidence of BGR on 11 rice cultivars in 1998-2000 (Fig. 5). The regression equation was highly significant ($p \leq 0.01$) and the coefficient of determination (R^2) was 0.806, suggesting that 80.6% of variation in the log-transformed disease incidence was accounted for by C_{inf}. According to the regression equation, when $C_{inf} = 0.4$ and 1.0, estimated disease incidence is approximately 1.0% and 4.0%, respectively.

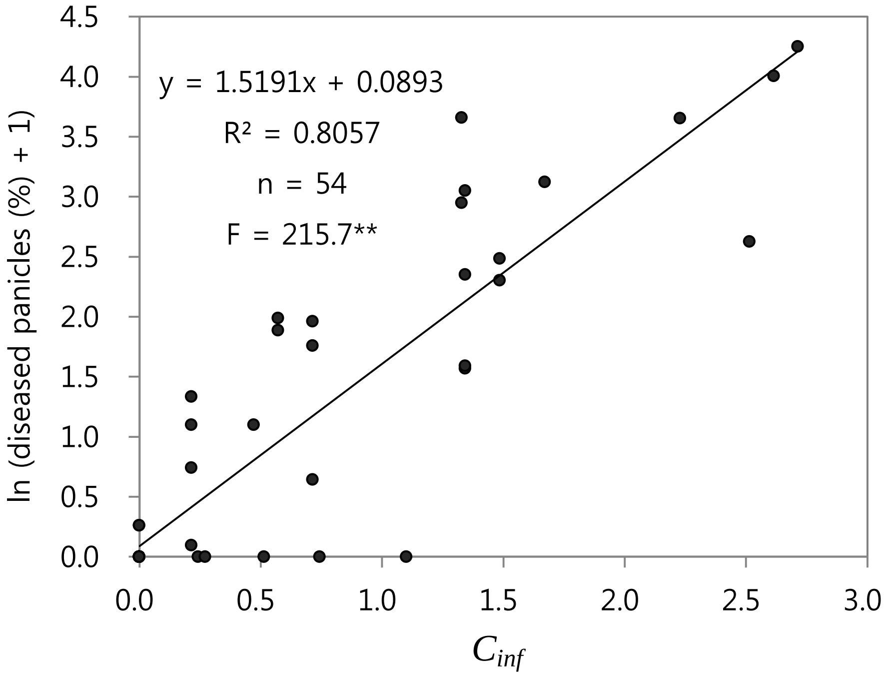


Fig. 5. Relationship between C_{inf} and log-transformed disease incidence in1998-2000.

Ⅴ. Thresholds of C_{inc} and C_{inf}.

Decisions were made to determine the thresholds of C_{inc} and C_{inf} considering their relationship with disease incidence in 1998-2000. In this study, we decided the thresholds of C_{inc} and C_{inf} to be 0.3 and 0.5, respectively. According to the regression equation in Fig. 5, disease incidence for $C_{inf} = 0.5$ would be 1.34%, which means that less than one panicle is diseased in a hill with 30 panicles. As for C_{inc}, the scatter diagram for C_{inc} and log-transformed disease incidence in Fig. 6A was examined to determine the threshold of C_{inc}. Data points in the diagram was divided into two groups; one with $C_{inc} < 0.3$ and the other with $C_{inc} \geq 0.3$. The former included 19 cases and the latter 35 cases. It was noticed that 20 out of 35 cases in the latter group had disease incidence of 0% and 18 of the 20 cases had $C_{inf} = 0.0$. The scatter diagram of 226 data points from 2001-2004 and 2010 also showed two groups clearly with regard to C_{inc} (Fig. 6B).

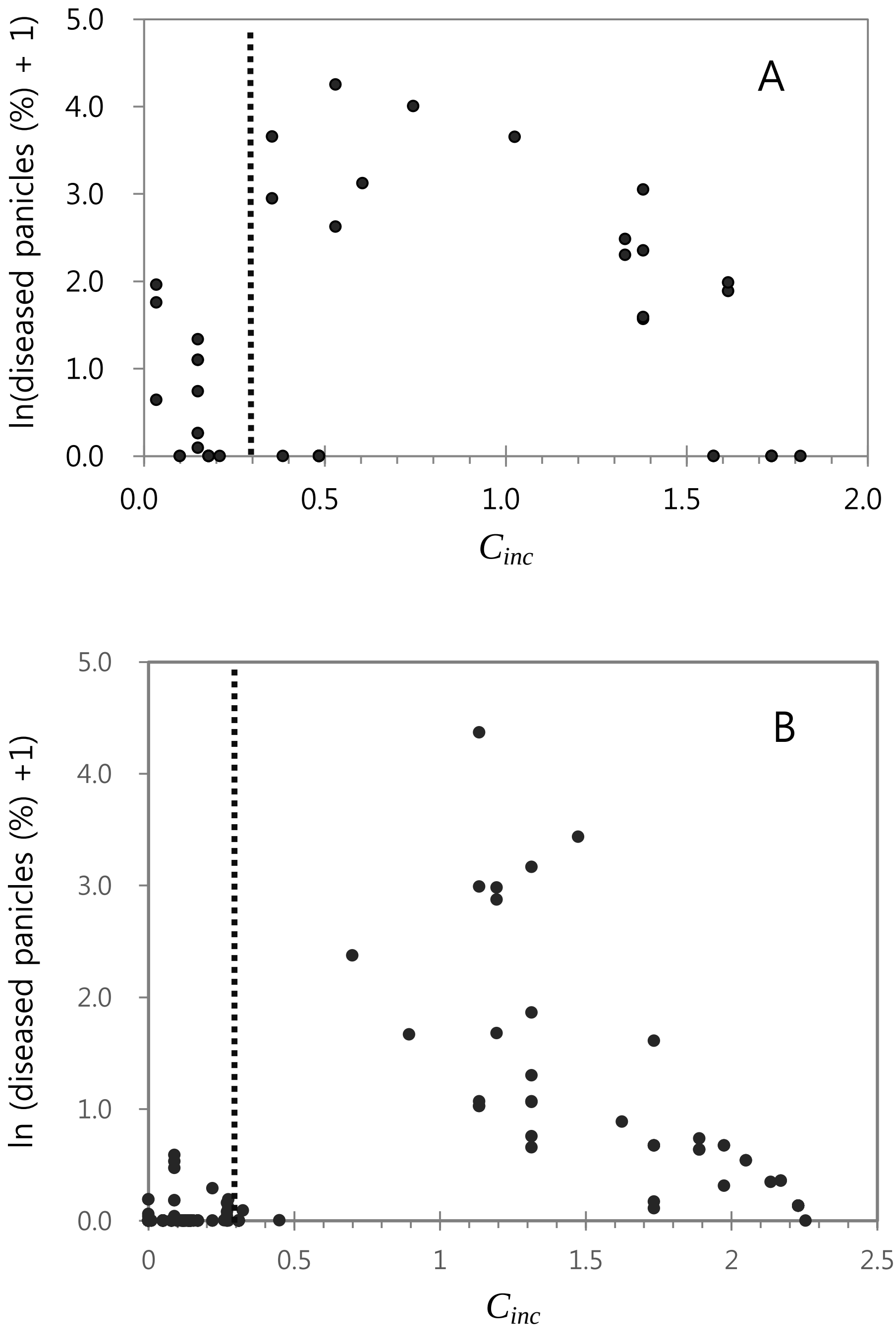


Fig. 6. Scatter diagrams for C_{inc} and log-transformed disease incidence in 1998-2000 (A) and in 2001-2004 and 2010 (B).

Ⅵ. Model validation and application

Using the BGRcast model, the environmental conduciveness to BGR development, which was represented by C_i, C_{inc} and C_{inf}, was calculated for 2001-2004 and 2010 (Fig. 7). The daily conduciveness, C_i, showed differences in weather conditions for BGR between years, being most favorable in 2010. In general, weather conditions in 2001-2004 were not favorable for BGR development. The C_{inc} indicated that environmental conduciveness of weather conditions during mid- and late July in 2001-2004 appeared minimal to support inoculum build-up of *B. glumae*, whereas it was high in 2010. The environmental conduciveness during the heading stage of rice plants, which was expressed in C_{inf}, was very low in 2001-2004. The C_{inf} remained high throughout the heading stage of rice plants, except for 21 August, in 2010.

Using 226 data sets from 2001-2004 and 2010, a regression analysis was conducted to determine quantitative relationship between C_{inf} and log-transformed disease incidence of BGR (Fig. 8). The regression equation was highly significant ($p \leq 0.01$) and the coefficient of determination (R^2) was 0.559, suggesting that 55.9% of variation in the log-transformed disease incidence was accounted for by C_{inf}. Of 226

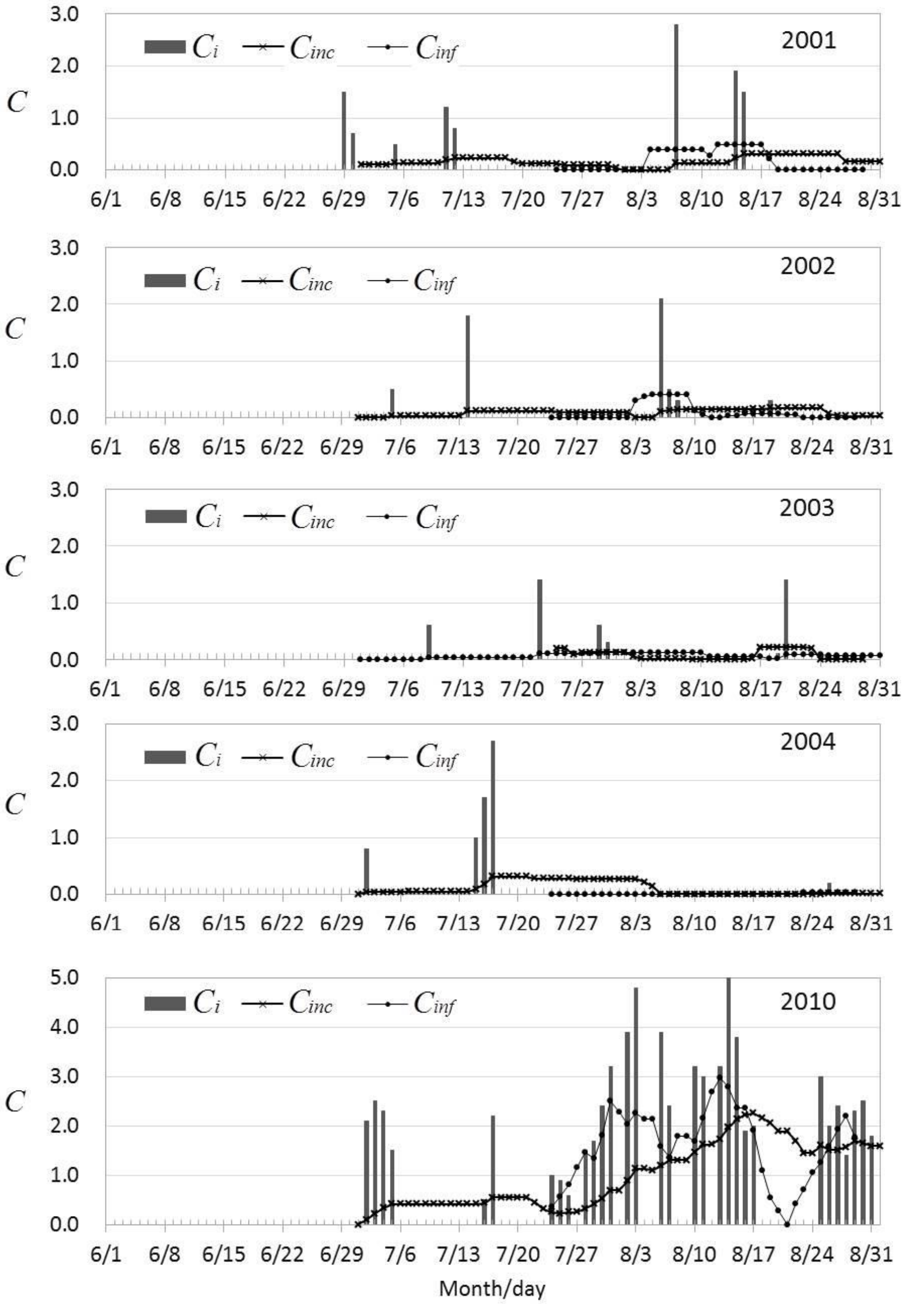


Fig. 7. Temporal change of and C_i, C_{inf}, and C_{inc} calculated by the BGRcast model using weather data from 2001-2004 and 2010.

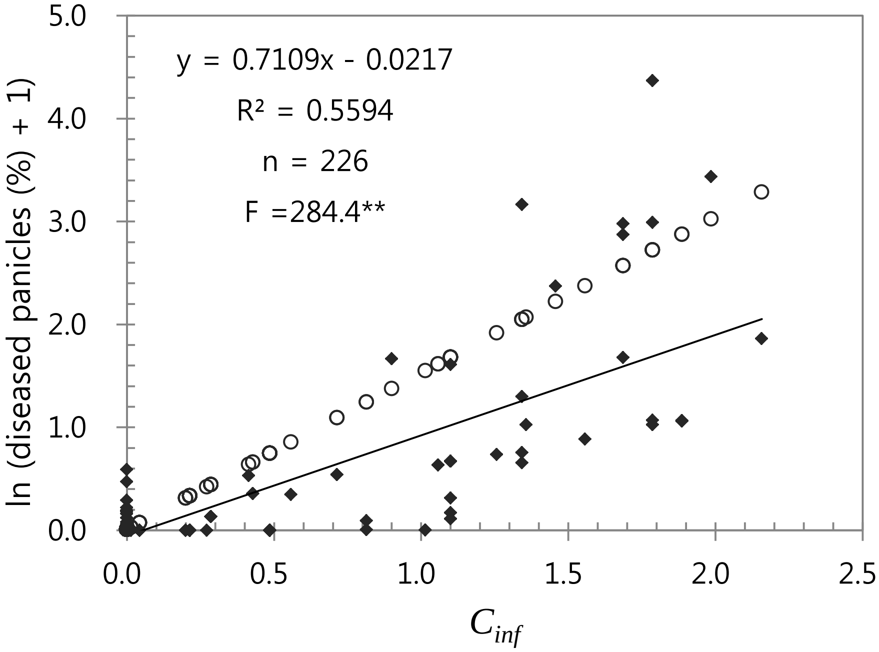


Fig. 8. Relationship between C_{inc} and log-transformed disease incidence in 2001-2004 and 2010. The open circles are log-transformed disease incidence expected by the regression equation that was determined based on the data from 1998-2000.

data points used in the regression analysis, disease incidence of 163 data points was zero. The disease incidence in 2001-2004 and 2010 was lower than the expected by the regression equation in Fig. 5, which was determined based on the data from 1998-2000.

The BGRcast model was evaluated for its capacity in determining possible occurrence of BGR using the two-way contingency table analysis (Table 3). Disease events regardless of severity of disease incidence have occurred in 27.9% cases of 226 data points. The disease forecast hit in the cases of 19.9% and missed 8.0% cases. Consequently, POD by the disease forecast was 71.4% of actual disease occurrences. The disease forecast resulted in false alarm for disease events in 13.3% cases, and FAR was 47.6%. The FAR is the percent of forecasting disease development that did not occur in reality. The bias score was 1.19, suggesting that the BGR forecast model could forecast risk of BGR development slightly more frequently than actual development of the disease.

Recommendations for bactericide sprays at the pre- and post-heading stage were presented in Table 4 as compared with disease incidence that occurred without any bactericide sprays. As shown in Fig. 7, conduciveness of weather conditions to BGR development was minimal in 2001, whereas it was high in 2010. Four cultivars were selected

Table 3. Results of the two-way contingency table analysis to evaluate accuracy of disease forecasts by the BGRcast model as compared with the observed disease occurrence in 2001-2004 and 2010. A total of 226 data points were included in the analysis

Index[a]	Categorical score of disease incidence event
Hit	19.9 %
Miss	8.0 %
False alarm	13.3 %
Correct rejection	58.8 %
Probability of detection (POD)	71.4 %
False alarm ratio (FAR)	47.6 %
Bias score	1.19

[a] Hit, miss, false alarm, and correct rejection are relative frequency that disease occurred in both the observed and the forecast, disease occurred in the observed but it did not in the forecast, disease did not occur in the observed but it occurred in the forecast, and disease did not occur in both the observed and the forecast, respectively. POD=Hit/(Hit+Miss). FAR=False alarm/(Hit+False alarm). Bias score = Forecast(False alarm+Hit)/Observed (Miss+Hit).

Table 4. Results of C_{inc} and C_{inf} and advisories for bactericide sprays at the pre- and post-heading stage determined by the daily conduciveness model for selected rice cultivars in 2001 and 2010

Transplanting date			30 May						15 June					
Year	Maturity Types	Cultivars	Heading date	Diseased panicles (%)	C_{inc}	C_{inf}	Pre-heading spay	Post - heading spay	Heading date	Diseased panicles (%)	C_{inc}	C_{inf}	Pre - heading spay	Post - heading spay
2001	Early	Odae	29 July	0.0	0.10	0.00	x	x	12 Aug	0.0	0.14	0.49	○	x
`	Middle	Sura	7 Aug	0.0	0.00	0.40	x	x	19 Aug	0.0	0.31	0.00	○	x
	Middle	Shindongjin	10 Aug	0.0	0.00	0.40	○	x	21 Aug	0.0	0.31	0.00	○	x
	-to- late	Ilpum	14 Aug	0.0	0.14	0.49	○	x	24 Aug	0.0	0.31	0.00	○	x
2010	Early	Manna	30 July	0.0	0.26	1.81	○	○	12 Aug	1.9	1.32	2.70	○	○
	Middle	Haechanmul	8 Aug	4.3	1.14	1.79	○	○	17 Aug	1.0	1.74	1.91	○	○
	Middle	Ilmi	14 Aug	30.0	1.48	2.80	○	○	20 Aug	0.1	2.23	0.29	○	x
	-to- late	Jinbaek	17 Aug	4.0	1.74	1.91	○	○	25 Aug	0.9	1.89	1.26	○	○

* If $C_{inc} > 0.3$, then the pre-heading spray was recommended. If C_{inf}>0.5, then post- heading spray was recommended. If $C_{inc} = 0$, then no spray was recommended at both of the pre- and post-heading stage.

each year from 29 and 23 rice cultivars in 2001 and 2010, respectively. Rice cultivars, rice maturity types, transplanting dates, heading dates and disease incidence were taken into consideration to select rice cultivars each year. Differences in C_{inc} and C_{inf} were noted between cultivars and between transplanting dates. Based on the thresholds of C_{inc} (0.3) and C_{inf} (0.5), recommendations were made for bactericide sprays at the pre- and post-heading stage of rice plants, respectively. The results showed that cultivar Odae needed no sprays at all regardless of transplanting dates in 2001. For cultivars Sura, Shindongjin and Ilpum transplanted on 15 June, C_{inc} was $\geq$ 0.3 and one spray at the pre-heading stage was recommended. With regard to the cases in 2010, cultivar Manna was recommended one spray at the post-heading stage when transplanted on 30 May. However, both sprays at the pre- and post-heading stage might have been necessary, when cultivar Manna was transplanted late on 15 June. For cultivar Ilmi, both sprays were advised if transplanted 30 May, whereas it was probably needed to make one spray at the pre-heading stage when transplanted late on 15 June. Cultivars Haechanmul and Jinback were recommended two sprays at both the pre- and post-heading stage regardless of transplanting dates in 2010.

DISCUSSION

A daily conduciveness model was developed to forecast risk of BGR by estimating environmental conduciveness to the disease development using daily weather data. Epidemiological knowledge regarding effects of weather conditions on development of the disease was adopted from the literature (Cha et al., 2001; Hikichi, 1993c; Tsushima, 1996; Tsushima et al., 1985; Tsushima et al., 1995a; Tsushima et al., 1996; Yokoyama and Okuhara, 1987). Information on population dynamics of *B. glumae* in association with rice plants and effects of weather factors on BGR development were taken into special consideration in the process of model development.

The concept of disease triangle in plant pathology is the central theorem of the BGR forecast model, stating that if bacterial inoculum is available at the right time of rice plant development, then successful infections occur under favorable environmental conditions. The environmental conduciveness proposed in this study is a measure of conduciveness of weather conditions for population growth of *B. glumae* and panicle infection by the bacteria in the field. The disease triangle concept was fully exploited in the BGR forecast model by introducing the environmental conduciveness and defining the three phases of epidemic development of BGR in relation to the development stages of rice plants.

Disease incidence of BGR and heading dates of rice plants are affected by weather conditions (Lee et al., 2004; Yokoyama and Okuhara, 1987; Oldeman et al., 1987). The difference in heading date and BGR incidence of a rice cultivar between transplanting dates in Table 1 suggested that the variations in disease incidence was due to difference in weather conditions at the different time-windows of heading stage. Difference in disease incidence between rice cultivars was also observed in 1998. However, no disease occurred in 1999 on all rice cultivars tested and cultivar resistance to BGR could not be confirmed in this study. No single gene resistance to BGR has been found yet and a QTL on chromosome 1 that controls BGR resistance has been reported (Mizobuchi et al., 2013; Pinson et al., 2010). Therefore, the variation in disease incidence observed in this study was considered to be mainly due to weather conditions rather than difference in disease resistance between rice cultivars. Severe occurrence of BGR on rice plants with heading dates in mid-August regardless of rice cultivars in 1998 supported the fact that weather conditions during the heading stage of rice plants were crucial for BGR development.

In the BGRcast model, $Tn_{base} = 22$℃ and $RH_{base} = 80\%$ were selected empirically based on the data from 1998-2000. Coincidentally, Mogi and Tsushima (1984) reported that BGR occurred severely when daily minimum temperature was 22-23℃ during the second half of rice growth period. Yokoyama and Okuhara (1987) also reported that BGR occurred severely when the average daily minimum temperature was 23℃ during the five days in the middle of heading stage of rice plants with rainfall of 5-30mm/day. With regard to relative humidity, humid conditions or rainfall were emphasized in order to have severe disease incidence, but no specific relative humidity was reported to be a minimum for BGR (Lee et al., 2004; Yokoyama and Okuhara, 1987). By having $RH_{base} =$ 80% in the BGRcast model, dry conditions that would not be favorable for bacterial growth and infection were eliminated from the calculation of environmental conduciveness.

The duration of inoculum build-up phase was determined to be 20 days backward from the date of first panicle emergence. The 20 days prior to the first panicle emergence are approximately the period of booting stage of rice plants (Lee, 2010; Moldenhauer and Slaton, 2001). It has been reported that bacterial population of *B. glumae* on the upper leaf sheaths at the booting stage affected disease incidence of BGR (Hikichi, 1993c; Tsushima et al., 1991; Tsushima and Naito, 1991; Tsushima, et al., 1996). The C_{inc} was considered a measure of weather conditions affecting the availability of active inoculum for panicle infection.

The C_{inf} indicated conduciveness of weather conditions for panicle infection during 7 days of the heading stage of rice plants. It usually takes 7 days from the first panicle emergence to have the last effective panicle emerged (Lee, 2010). It was also observed in the field that more than 80% of panicles have emerged during the 7 days in all rice cultivars. In this study, the date of first panicle emergence was determined to be 3 days prior to the heading date that was observed in the field. By defining C_{inc} and C_{inf} in relation to the date of first panicle emergence and the heading stage of rice plants, they can be used in general terms representing environmental conduciveness regardless of rice cultivars, transplanting dates, locations, year etc. Consequently, the BGRcast model can be applicable widely for diverse rice management systems with different rice cultivars.

Temporal changes of C_i, C_{inc} and C_{inf} in Fig. 4 indicated how favorable the weather conditions were for BGR development in 1998-2000. The difference in disease incidence among the three years was well reflected by C_{inc} and C_{inf}. Considering C_{inc} and C_{inf} together, infection risk by *B. glumae* in 1998 was high, and very low in 1999 and 2000. In 1998, weather conditions were highly conducive for BGR development from late July to 21 August. From 22 August, 1998, C_{inf} remained zero, suggesting that risk of panicle infection by the bacteria would be very low if the heading date was later than 21 August. It was interesting to note that no disease development was observed when the heading date was later than 21 August in 1998 regardless of rice cultivars.

The regression equation in Fig. 5 was an empirical model describing the relationship between C_{inf} and log-transformed disease incidence in 1998-2000. Statistical significance of the regression equation implied that C_{inc} and C_{inf} could be used to represent conduciveness of weather conditions to BGR development. However, the regression equation overestimated log-transformed disease incidence in the validation test using the data from 2001-2004 and 2010 in Fig. 8. In the validation tests, the BGRcast model identified differences between years in conduciveness of weather conditions for BGR development. The apparent differences in disease incidence among 2001-2004 and 2010 were reflected in the differences in C_i, C_{inc} and C_{inf}. The capacity of the model to forecast possible risk of BGR was proven by the statistical significance of regression equation in Fig. 8. However, the regression equation was different from the one determined based on the data from 1998-2000 in Fig. 5. Therefore, it was concluded that the

BGRcast model in this study could be used to forecast possible risk of BGR based on daily weather data, but it might not be capable of estimating amount of disease incidence. In the two-way contingency table analysis in Table 3, it was found that 71.4% of the cases of BGR occurrence were forecasted correctly by the model and 47.6% of its warnings were untrue. As suggested by the bias score of 1.19, slightly more frequent warnings could be made by the model as compared with actual occurrence of BGR. Consequently, the BGRcast model would help rice growers to be conservative in decision-making for chemical sprays.

The BGRcast model was tested for its effectiveness in decision-making for bactericide sprays in the field. For this application, decision-support advisories for eight rice cultivars were evaluated using the data from 2001 and 2010. By selecting the eight rice cultivars transplanted at 30 May and 15 June under unfavorable and favorable weather conditions, we were able to examine 16 cases with different C_{inc} and C_{inf}. The results in Table 4 suggested that the recommendations based on C_{inc} and C_{inf} appeared reasonable considering disease incidence that actually occurred without any bactericide sprays in 2001 and 2010. In the conventional spray program adopted by rice growers in Korea, two sprays at the pre- and post-heading stage are commonly recommended and the first spray at the pre-heading stage is considered more important than the other (Hikichi and Egami, 1995; Isogawa et al., 1989; KCPA, 2014). In the cases of cultivars Sura, Shindongjin and Ilpum transplanted on 15 June, recommendation for just one spray at the pre-heading stage would be a safeguard for rice crop in 2001 considering the weather conditions prior to panicle emergence of the three cultivars. In 2010, it is interesting to note that disease incidence on early-transplanted cultivar Manna and late-transplanted cultivar Ilmi was close to 0% and the BGRcast model recommended just one spray at the post- and pre-heading stage, respectively. The savings of bactericide spray in the cases of cultivars Manna and Ilmi would be an advantage of implementing the BGR forecast model in 2010, during which weather conditions were generally favorable for the disease development. Consequently, the decision-making for bactericide sprays using the BGRcast model would be of help for rice growers to improve effectiveness of spray programs to control BGR. The thresholds of $C_{inc} = 0.3$ and $C_{inf} = 0.5$ were found to be appropriate in this study. Although multi-year data were used to determine the thresholds of C_{inc} and C_{inf}, further investigation is yet to be necessary to find an ideal threshold levels for common uses under various environmental conditions.

In this study, we have proposed C_{inc} and C_{inf} as a measure of conduciveness of weather conditions for population growth of *B. glumae* and panicle infection by the bacteria, respectively. Since C_{inc} and C_{inf} are calculated in relation to the first panicle emergence and the heading stage of rice plants, they can be used in comparative studies on BGR in the field. For example, it is difficult to evaluate disease resistance of rice cultivars with different heading stages in the field because difference in disease incidence of BGR may have been caused by differences in both disease resistance and weather conditions during the heading stages of rice cultivars. In this case, C_{inc} and C_{inf} can be used as a standardized measure of environmental effects on BGR development, so that the compounding effects due to differences in the heading stage could be eliminated.

In conclusion, the BGRcast model was found to be useful in identifying weather conditions conducive to BGR development based on daily minimum temperature and average relative humidity. The model was also able to determine whether to spray bactericides to control the disease. By defining three phases of epidemic development of BGR in relation to panicle emergence of rice plants, the BGRcast model could be used for diverse rice management systems regardless of rice cultivars and cropping systems. With the thresholds of $C_{inc} = 0.3$

and $C_{inf} = 0.5$, the model could be used to determine whether to spray bactericide at the pre- and post-heading stage sprays to improve effectiveness of the conventional spray program to control BGR. Further evaluation on the BGRcast model along with bactericide spray programs is necessary to implement the model for practical use by rice growers.

LITERATURE CITED

Andrea, Q.-G. and Fernando, G.-S. 2014. *Burkholderia glumae* in the rice crop in Costa Rica. *Agron. Mesoam* 25:371-381.

Azegami, K., Nishiyama, K., Watanabe, Y., Kadota, I., Ohuchi, A. and Fukazawa, C. 1987. *Pseudomonas plantarii* sp. nov., the causal agent of rice seedling blight. *Int. J. Syst. Bacteriol.* 37:144-152.

Cha, K. H., Lee, Y. H., Ko, S. J., Park, S. K. and Park, I. J. 2001. Influence of weather condition at heading period on the development of rice bacterial grain rot caused by *Burkholderia glumae. Res. Plant Dis.* 7:150-154 (in Korean).

Goto, T. and Ohata, K. 1956. New bacterial diseases of rice (brown stripe and grain rot). *Ann. Phytopathol. Soc. Jpn.* 21:46-47 (in Japanese).

Ham, J. H., Melanson, R. A. and Rush, M. C. 2010. *Burkholderia glumae*: next major pathogen of rice? *Molecular Plant Pathology* 12:329-339.

Hikichi, Y. 1993a. Mode of action of oxolinic acid against bacterial seedling rot of rice caused by *Pseudomonas glumae*. Ⅰ. Relationship between population dynamics of *P. glumae* on seedlings of rice and disease severity of bacterial seedling rot of rice. *Ann. Phytopath. Soc. Jpn.* 59:441-446.

Hikichi, Y. 1993b. Mode of action of oxolinic acid against bacterial seedling rot of rice caused by *Pseudomonas glumae*. II . Efficacy of oxolinic acid against secondary infection. *Ann. Phytopath. Soc. Jpn.* 59:447-451.

Hikichi, Y. 1993c. Relationship between population dynamics of *Pseudomonas glumae* on rice plants and disease severity of bacterial grain rot. *J. Pesticide Sci.* 18:319-324.

Hikichi, Y. and Egami, H. 1995. Control system for bacterial grain rot of rice with oxolinic acid and seed selection with salt solution. *Ann. Phytopathol. Soc. Japan* 61:405-409 (in Japanese).

Hikichi, Y., Egami, H., Oguri, Y. and Okuno, T. 1998. Fitness for survival of *Burkholderia glumae* resistant to oxolinic acid in rice plants. *Ann. Phytopathol. Soc. Jpn.* 64:147-152.

Hikichi, Y., Okuno, T. and Furusawa, I. 1993. Immunofluorescent antibody technique for detecting *Pseudomonas glumae* on rice plants. *Ann. Phytopath. Soc. Jap.* 59:477-480 (in Japanese).

Hikichi, Y., Okuno, T. and Furusawa, I. 1994. Susceptibility of rice spikelets to infection with *Pseudomonas glumae* and its population dynamics. *J. Pesticide Sci.* 19:11-17.

Hikichi, Y., Okuno, T. and Furusawa, I. 1995. Mode of action of oxolinic acid against bacterial seedling rot or rice caused by *Pseudomonas glumae*. Ⅲ. Infection with *P. glumae* into plumules. *Ann. Phytopath. Soc. Jpn.* 61:134-136.

Isogawa, Y., Kato, S. and Li, S. H. 1989. Studies on environmental factors and control methods of bacterial grain rot of rice caused by *Pseudomonas glumae* Kurita and Tabei. II. Chemical control methods. *Research Bulletin of the Aichi-Ken Agricultural Research Centre* 21:85-90 (in Japanese).

Jeong, Y., Kim, J., Kim, S., Kang, Y., Nagamatsu, T. and Hwang, I. 2003. Toxoflavin produced by *Burkholderia glumae* causing rice grain rot is responsible for inducing bacterial wilt in many field crops. *Plant Dis.* 87:890-895.

Jolliffe, I. T. and Stephenson, D. B. 2003. Forecast verification: A practitioner`s guide in atmorspheric science. John Wiley & Sons Ltd, West Sussex, England. pp. 240.

KCPA. 2014. Agrochemicals use guide.edited by Korea Crop Protection Association. Samjung Publication, Seoul, Korea (in Korean).

Kim, J., Kang, Y., Kim, J.-G., Choi, O. and Hwang, I. 2010. Occurrence of *Burkholderia glumae* on rice and field crops in Korea. *Plant Pathol. J.* 26:271-272.

Kurita, T. and Tabei, H. 1967. On the causal bacterium of grain rot of rice. *Ann. Phytopath. Soc. Jap.* 33:111 (in Japanese).

Lee, C. W. 2010. Heading, flowering and fertilization. In: *Rice*, eds. by Koean Research Society of Rice, pp. 207-214. KNOU-PRESS, Seoul, Korea (in Korean).

Lee, Y. H., Ko, S. J., Cha, K. H., Choi, H. G., Lee, D. G., Noh, T. H., Lee, S. D. and Han, S.-S. 2004. Micro-weather factors during rice heading period influencing the development of rice bacterial grain rot. *Res. Plant Dis.* 10:167-174 (in Korean).

Lee, Y. H., Ra, D.-S., Yeh, W.-H., Choi, H.-W., Myung, I.-S., Lee, S.-W., Lee, Y.-H., Han, S.-S. and Shim, H. S. 2010. Survey of major disease incidence of rice in Korea during 1999-2008. *Res. Plant Dis.* 16:183-190 (in Korean).

Luo, J., Xie, B. and Lilhui, X. 2007. First report of *Burkholderia glumae* isolated from symptomless rice seeds in China. *Plant Dis.* 91:1363.

Mizobuchi, R., Sato, H., Fukuoka, S., Tanabata, T., Tsushima, S., Imbe, T. and Yano, M. 2013. Mapping a quantitative trait locus for resistance to bacterial grain rot in rice. *Rice* 6:13.

Mogi, S. and Tsushima, S. 1984. Recent epidemic development and ecology of bacterial grain rot of rice. *Annual Report of the Kyushu Agricultural Experiment Station* 22:47-53 (in Japanese).

Moldenhauer, K. and Slaton, N. 2001. Rice growth and development. In: *Rice Production Handbook. Misc. Publ. 192*, eds. by N.A. Slaton, pp. 7–14. Coop. Ext. Service, University of Arkansas, Little Rock, USA.

Nandakumar, R., Shahiahan, A. K. M., Yuan, X. L., Dickstein, E. R., Groth, D. E., Clark, C. A., Catwright, R. D. and Rush, M. C. 2009. *Burkholderia glumae* and *B. gladioli* cause bacterial panicle blight in rice in the southern United States. *Plant Dis.* 93:896-905.

Oldeman, L. R., Seshu, D. V. and Cady, F. B. 1987. Response of rice to weather variables. In: *Weather and rice*, pp 5-39. IRRI, Laguna, Philippines.

Pinson, S. R. M., Shahjahan, A. K. M., Rush, M. C. and Groth, D. E. 2010. Bacterial panicle blight resistance QTLs in rice and their association with other disease resistance loci and heading date. *Crop Science* 50:1287-1297.

Riera-Ruiz, C., Vargas, J., Cedeno, C., Quirola, P., Escobar, M., Cevallos-Cevallos, J. M., Ratti, M. and Peralta, E. L. 2014. First report of *Burkholderia glumae* causing bacterial panicle blight on rice in Ecuador. *Plant Dis.* 98:988-989.

Shahjahan, A. K. M., Rush, M. C., Groth, D. and Clark, C. A. 2000. Panicle blight. *Rice J.* 15:26-29.

Sokal, R. R. and Rohlf, F. J. 1973. Introduction to biostatistics. W. H. Freeman and Company, San Francisco. 368 pp.

Takashi, H. and Hideo, I. 2013. Chemical control of plant diseases. *J. Gen. Plant Pathol.* 79:390-401.

Trung, H. M., Van, N. V., Vien, N. V., Lam, D. T. and Lien, M. 1993. Occurrence of rice grain rot disease in Vietnam. *Int. Rice Res. Notes* 18:30.

Tsushima, S. 1996. Epidemiology of bacterial grain rot of rice caused by *Pseudomonas glumae*. *Japan Agricutural Research Quaterly* 30:85-89.

Tsushima, S., Mogi, S., Naito, H. and Saito, H. 1991. Population of *Pseudomonas glumae* on rice plants. *Ann. Phytopath. Soc. Jap.* 57:145-152.

Tsushima, S., Mogi, S. and Sato, H. 1985. Effect of inoculum density, incubation temperature and incubation period on the development of rice bacterial grain rot. *Proc. Assoc. P1. Prot. Kyushu* 31:11-12 (in Japanese).

Tsushima, S. and Naito, H. 1991. Spatial distribution and dissemination of bacterial gain rot of rice caused by *Pseudomonas glumae*. *Ann. Phytopath. Soc. Jap.* 57:180-187.

Tsushima, S., Naito, H. and Koitabashi, M. 1995a. Change in panicle susceptibility associated with flowering rate of spikelets in bacterial grain rot of rice caused by *Pseudomonas glumae*. *Ann. Phytopath. Soc. Jpn.* 61:109-113.

Tsushima, S., Naito, H. and Koitabashi, M. 1995b. Forecast of yield loss suffered from bacterial grain rot of rice in paddy fields by severely diseased panicles. *Ann. Phytopath. Soc. Jpn.* 61:419-424.

Tsushima, S., Naito, H. and Koitabashi, M. 1996. Population dynamics of *Pseudomonas glumae*, the causal agent of bacterial grain rot of rice, on leaf sheaths of rice plant in relation to disease development in the field. *Ann. Phytopath. Soc. Jpn.* 62:108-113.

Urakami, T., Ito-Yoshida, C., Araki, H., Kijima, T., Suzuki, K. I. and

Komagata, K. 1994. Transfer of *Pseudomonas plantarii* and *Pseudomonas glumae* to *Burkholderia* as *Burkholderia* spp. and description of *Burkholderia vandii* sp. nov. *Int. J. Syst. Bacteriol.* 44:235-245.

Yokoyama, T. and Okuhara, K. 1987. Relationship between the occurrence of rice bacterial grain rot and meteorological conditions and cultivars of rice. *Proc. Assoc. Pl. Prot. Kyushu* 33:4-8 (in Japnases).

CHAPTER 2.

Implementation of the BGRcast model

in the National Crop Pest Management System

ABSTRACT

National Crop Pests Management System (NCPMS) is monitoring and forecasting crop diseases and pests (CDP) as well as delivering its information to crop growers or extension specialists. NCPMS is composed of three main systems, monitoring, forecasting and diagnosis of CDP. Currently, BGRcast, bacterial grain rot forecast model, is being used in NCPMS to support rice growers who are keen to spray chemicals only when infection risk of *Burkholderia glumae* is high enough to cause significant yield loss. The forecast information is alarmed by short message service (SMS) automatically at 7 AM according to the user`s request. Users who visit the website and receive SMS of disease forecast have been increasing every year after opening the forecast service. Comparing maps of forecast from interpolated weather data with BGR incidence area in 2010-2014, the more area of high level of threshold showed on the web map, the higher disease incidence area monitored.

Keywords: National Crop Pests Management System (NCPMS), web-based forecasting system

INTRODUCTION

One of the epidemiological strategies to minimize losses due to plant disease is to eliminate or reduce the initial inoculums (Magarey et al., 2007). Farmers, generally, prefer to spray chemical for control the disease rather than the other control strategies in Asia (Takashi and Hideo, 2013). It is essential that to spray chemicals on optimal time is for eliminating or reducing the initial inoculums. Ironically, it is difficult for farmers to find out an optimal time for control at early infection. The prediction of plant diseases has developed as a well-established component of epidemiology into disease management.

Presently, the completely new advances in information technology and the Internet, as well as the global connectivity and integration with modern programming language, have produced new ideas and ways to be explored further in the production and transfer of knowledge. Advances in web-based technologies are bringing major changes in the development and use of decision-support systems by farmers and specialists in the management of plant diseases (Fernandes et al. 2007).

It is necessary that farmers monitor and identify exactly the disease. Extension officers in Rural Development Administration, federal extension services, and local agricultural technology center have monitored disease and then delivered disease control information to farmers in Korea. Due to decreasing the manpower of extension services has been decreased, it is necessary to develop a new system for delivering disease control information. Delivered information on disease forecasting and monitoring can assist farmers or extension specialists in determining management which is needed to control a specific crop disease. Especially, attempts to provide the disease forecasts based on the meteorological data for the farmers have been tried in many studies (Russo and Zack, 1997; Roberts et. al. 2006; Pavan et al. 2010). Recently, new information technology has provided various delivery system of information by which farmers or advisors can easily access to plant disease forecast information, such as personal computer with powerful computing resources, web-based internet system and wireless communication infrastructure (Kang et al., 2010). The simulation models for weather data analysis applied with geographic information system (GIS) have improved temporal and spatial resolution of weather data. Consequently, it could estimate site-specific weather information without on-site sensor (Kang, et al., 2010; Oldeman, et al., 1987; Russo and Zack, 1997). A web-based information system for plant disease forecast based on weather data at high spatial resolution of 240 m x 240 m has been serviced in Gyeonggi-do, Korea (Kang, et al., 2010). Risk maps on late blight leaded to a reduction in the frequency of fungicide applications and give better control of disease in Germany (Berger, 1977). A web-based disease forecasting system for strawberry had been successful in eliminating many unnecessary fungicide applications and had proven famer friendly (Pavan et al. 2010). A diverse array of pest information systems in the USA, such as a national Pest Platform for Extension and Education (PIPE), provide growers with valuable information for managing plant diseases, insect pests, and weed at local, regional, and national scales (Isard et al. 2006).

The main objectives of this study were to develop National Crop Pests Management System (NCPMS) and implement the BGRcast model with web-based forecasting system based on weather data at high spatial resolution in NCPMS to predict bacterial grain rot of rice and to help rice growers in Korea avoid unnecessary applications of bactericide and reduce production costs.

COMPORNENTS OF NCPMS

National Crop Pests Management System (NCPMS) has developed to monitor the diseases and pests (CDP) on 14 crops and to deliver the forecasting and monitoring information of CDP to the crop growers or extension specialists from 2011 by Rural Development Administration in Korea. NCPMS is designed to use contemporary information technology to carry the primary job of extension services more efficiently between the services and farmers.

The system is composed of three main information units; monitoring, forecasting and diagnosis of CDP (Fig. 1). In monitoring unit, disease incidence of 40 crop diseases and density of 45 insect species in the field of rice, barley, bean, hot pepper, garlic, onion, radish, Chinese cabbage, apple, pear, citrus, grape, peach and sweet persimmon. The monitored information was gathered every 7, 10, or 15 days through monitoring system of NCPMS. Monitoring is carried out by specialists of 9 federal extension services and 143 local agricultural technology centers. The monitoring sites are chosen by the local extension specialists of a region and are representative for the region. Users can see degree of CDP occurrence by everyday through the web GIS on the main page of NCPMS (Fig. 2) and download the data as an excel file. Degree of CDP is shown by different colors according to six level of

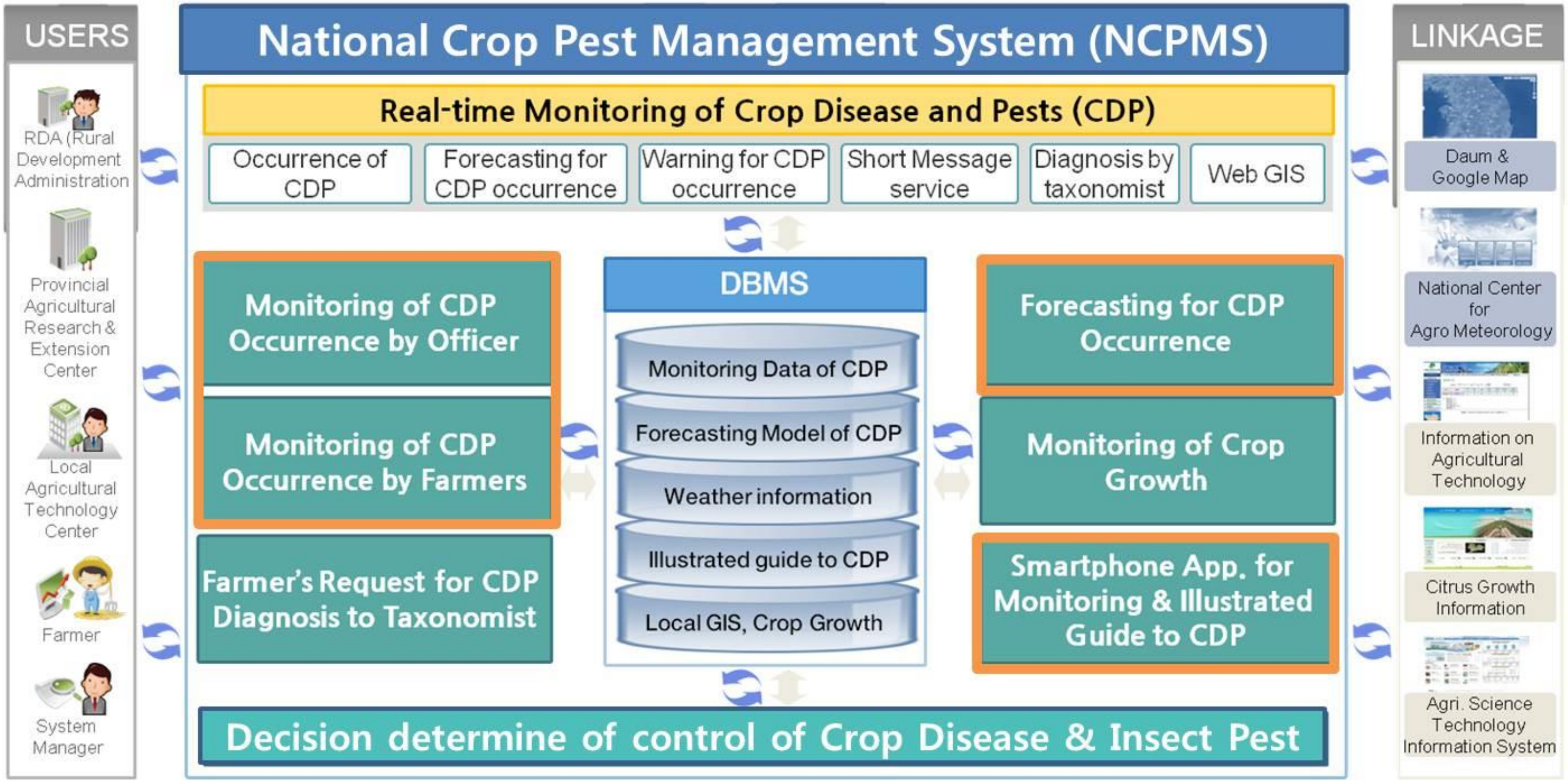


Fig. 1. Schematic diagram for structure of National Crop Pests Management System (NCPMS).

Fig. 2. The homepage screen shot of NCPMS: http;//ncpms.rda.go.kr/. Monitoring results of CDP in real time shown on the main page of NCPMS (red box).

CDP: zero, extremely weak, weak, moderate, severe, and sincerely severe.

Etiological characteristics and pictures of typical symptoms of plant diseases and insect pests can be found in diagnosis unit (Fig. 3). Data base of CDP contain the information of 6 grain crops including rice, 9 fruit trees including citrus, 47 flowering plants including rose, 30 vegetables including eggplant, 17 cash crops including cotton and 753 weeds including Aegimancho. If farmers or extension officer cannot ascertain CDP species by themselves, they can ask identification of the CDP to taxonomists, who composed of specialist on plant disease, insect pests, and weed in RDA and federal research services, through the web page or smartphone application and then receive the result by SMS or smartphone app. CDP diagnosis app can be downloaded for free from app market.

The forecasting unit is a web-based information system for plant diseases and insect pests forecast based on weather data at spatial resolution. The system produces daily alarms at the spatial resolution of 960m X 960m based on weather data from Korea Meteorological Administration (KMA). In this study, we describe a web-based information system for the forecast of bacterial grain rot (BGR) of rice for farmers or advisors in Korea. We validate the web map forecast results comparing to the BGR incidence area in 2010-2014.

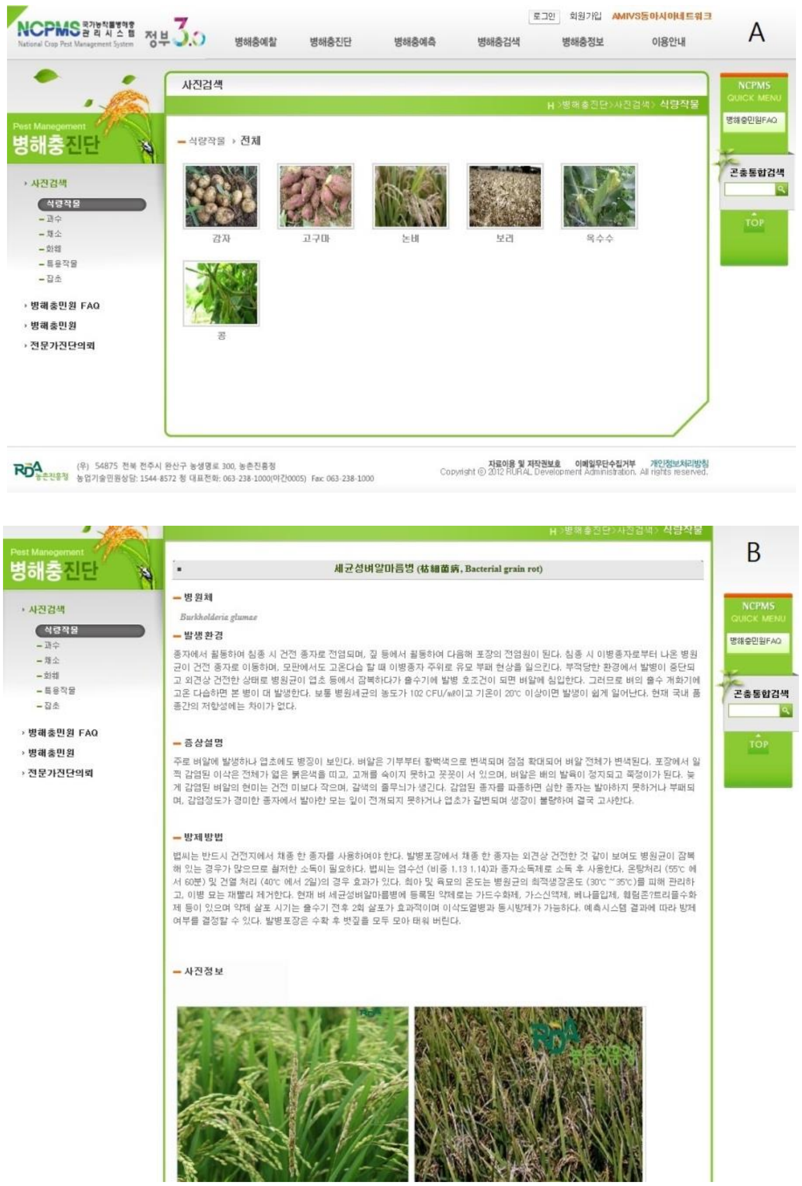


Fig. 3. Diagnosis main page of CDP (A) and an example of information of CDP (B), such as pathogen, symptoms, ecology, and control method *etc.* on NCPMS.

BGRcast implementation

Ⅰ. BGRcast implementation in NCPMS

BGR forecasting model, BGRcast, has two conduciveness parameters (C_{inc} and C_{inf}) for disease development. C_{inc}, built up phase of *B. glulme* on the rice plant before heading of rice, is a parameter for decision whether a chemical spray at just before first heading is needed or not. C_{inf} is a parameter for decision whether a chemical spray at the end of heading of rice based on weather condition during 7 days of heading period.

Two conduciveness parameters are shown through web map interface in NCPMS (Fig 4). A user selects the first heading forecast button or the 3 days after heading stage button on the user interface, then different color pattern is shown according to the level of C_{inc} of built up phase and C_{inf} of infection phase, respectively.

Rice farmers should be aware of the first heading or just before heading of rice in his field, and check the threshold level for 1st chemical spray then decide 1st spray based on BGR forecast interface in NCPMS web site. Second spray of chemical could be determined at 7 days after 1st spray, generally end of heading. The forecast information is alarmed by short message service (SMS) automatically at 7 AM according to the user`s selection of site. The users registered can select

Fig. 4. User interface of the disease forecasting system and example of rice bacterial grain rot forecast. The space resolution of disease forecast is 960m x 960m, and information on daily threshold level for 1st chemical spray at just before first heading is available for each grid on the map.

the alarmed area and period by themselves on the web service interface. Users of visiting the website and receiving SMS of disease forecast have been increasing every year after opening the forecast service (Table 1).

Ⅱ. Validation of BGRcast

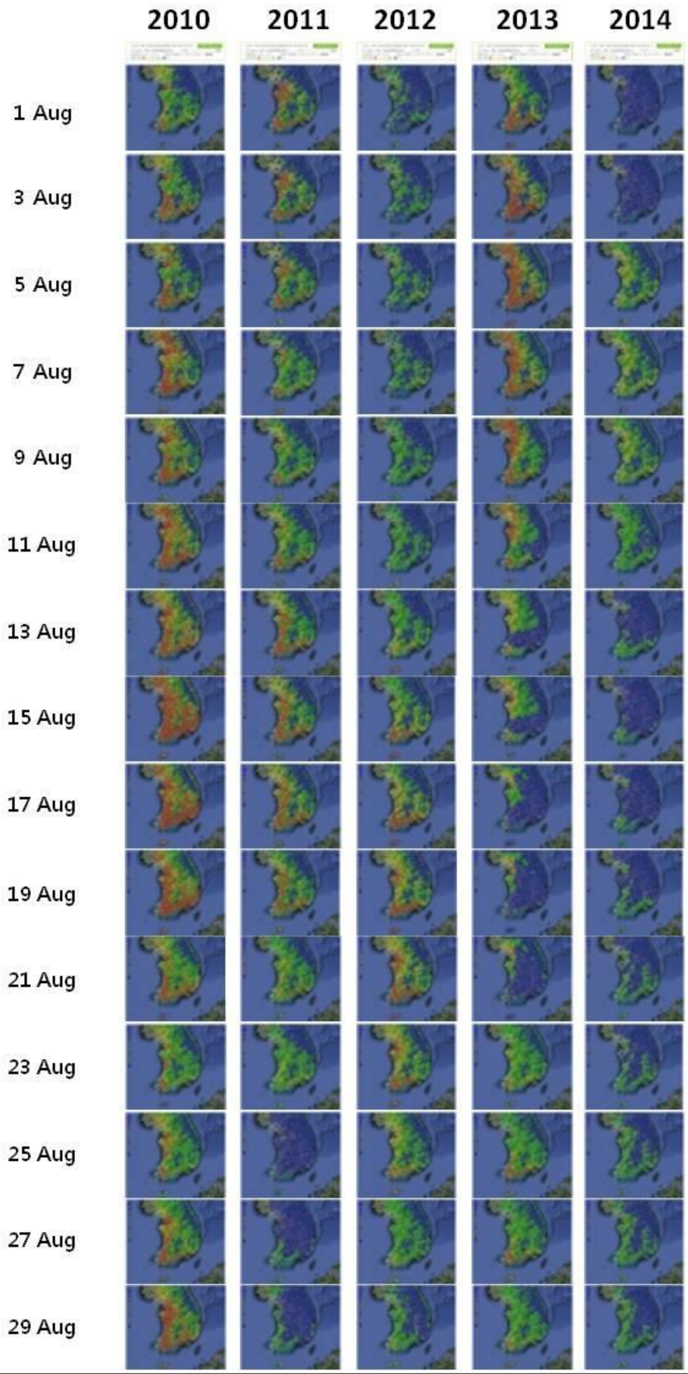
The accuracy in conduciveness parameter (C_{inf}) infection periods based on the interpolated weather data evaluated for August which favorable for BGR infection in 2010-2014. Maps of forecast results from interpolated weather data were compared to BGR incidence area (ha) investigated in 960 samples of rice monitoring fields nationwide by Rural Development Administration, federal Extension Services and local Agricultural Technology Center.

Comparing maps of forecast from interpolated weather data with BGR incidence area in 2010-2014, the more area of high level of threshold showed on the web map, the higher disease incidence area monitored (Fig. 4). In case 2010, almost area cultivated rice showed high level of threshold on the web map at almost every day in August, consequently diseased area was highest. In contrast, threshold level showed very low on the web map at almost every day in 2014, the lowest level of disease incidence showed.

Table 1. Statistics of web site visiting and SMS utilized

	2011	2012	2013	2014
No. of members (A)	1,136	2,258	3,285	4,013
No. of visit (B)	83,720	205,539	199,611	575,830
B/A	73.7	91.0	60.8	143.5
No. of SMS[a] (C)	8,546	11,894	29,082	52,956
C/A	7.5	5.3	8.9	13.2

[a] Short message service



	2010	2011	2012	2013	2014
Diseased Area (ha)	39,498	12,913	11,198	23,094	3,670

Fig. 5. Web map images of BGR forecast at day after heading period and BGR diseased area of rice in 2010-2014 in Korea.

DISCUSSION

Kang et al. (2010) suggested that forecast information system have to be site-specific, accurate, and near real-time delivery of disease forecasts, and easily accessed by uses. The BGR forecast model was implemented in NCPMS, in which the forecast information covering the whole country is delivered at the spatial resolution of 960 m x 960 m which is enough to produce site-specific disease forecasts in Korea. Disease forecasting information was produced automatically and weather data was delivered in real-time via National Agro Meteorological Administration (NAMC) from Korea Meteorological Administration (KMA). This is also a good example of cooperation between related organizations. Because interpolated weather data using Synoptic Weather Observation Network (SWON) and Automated Weather Station Network (AWSN) of KMA had the discrepancies between the observed and the interpolated data, and could not represent the microclimate within crop plant canopy (Kang, et al., 2010), BGRcast was analyzed using the data of SWON of Gwangju station. It was thought that BGR forecasting results through forecast web images could be predicted relatively accurate disease incidence. Conduciveness parameter of BGR forecasting model consists of minimum temperature and relative humidity. Because interpolated air temperature was accurate but relative humidity was often underestimated (Kang, et al., 2010), BGR forecast might be overestimated.

Users can easily find the field location because disease forecasts images was showed overlapped on the satellite images and a field address could be searched. Furthermore, users can be received forecast information automatically from NCPMS due to selecting the alarmed area and period by themselves.

Increasing in visit counts to NCPMS and in utilization of SMS was more rapid than increasing the number of members (Table 1). It is indicated that practical use of disease forecast models is increasing in Korea because NCPMS serviced exact forecasting information and could be easily accessed. Hopefully rice growers in Korea will benefit from the BGR forecast model through NCPMS, by which efficiency of chemical control would be increased for the BGR management of rice.

LIDTERATURE CITED

Berger, R. D. 1977. Application of epidemiological principles to achieve plant disease control. *Ann. Rev. Phytopathol.* 15: 165-181.

Isard, S. A., Russo, J. M. and DeWolf, E. D. 2006. The establishment of a National Pest Information Platform for Extension and Education. *Plant Health Progress* doi: 10.1094/PHP-2006-0915-01-RV, http://www.plantmanagementnetwork.org/pub/php /review/2006/plantform.

Fernandes, J., Ponte, E. D., Pavan, W. and Cunha, G. 2007. Web-based System to True-Forecast Disease Epidemics-Case Study for Fusarium Head Blight of Wheat. In: *Climate Prediction and Agriculture,* pp. 265-271. Springer, Berlin Heidelberg, Germany.

Kang, W. S., Hong, S. S., Han, Y. K., Kim, K. R., Kim, S. G. and Park , E. W. 2010. A Web-based Information System for Plant Disease Forecast Based on Weather Data at High Spatial Resolution *Plant Pathol. J.* 26: 37-48.

Magarey, R. D., Fowler, G. A., Borchert, D. M., Sutton, T. B., Colunga-Garcia, M. and Simpson, J. A. 2007. NAPPFAST: An Internet system for the weather-based mapping of plant pathogens. *Plant Dis.* 91: 336-345.

Pavan, W., Fraissse, C. W. and Peres, N. A. 2011. Development of a web-based disease forecasting system for a strowberries. *Computers and Electronics in Agriculture* 75: 169-175.

Roberts, M. J., Schimmelpfennig, D., Ashley, E., Livingston, M., Ash, M. and Vasavada, U. 2006. The value of plant disease Early-warning systems: A case study of USDA's Soybean rust coordinated framework. Economic Research Reports No. 18, USDA.

Röhrig, M. 2007. www.isip.de - online plant protection information in Germany. *Bulletin OEPP/EPPO Bulletin* 37: 350-352.

Russo, J. M. and Zack, J. W. 1997. Downscaling GCM output with a mesoscale model. *J. Envir. Management* 49: 19-29.

Sokal, R. R. and Rohlf, F. J. 1973. Introduction to biostatisics W. H. Freeman and Company San Francisco pp|.

Takashi, H. and Hideo, I. 2013. Chemical control of plant diseases. *J. Gen. Plant Pathol.* 79:390-401.

Yun, J. I., Cho, K. S., Hwang, H., Park , E. W. and Cho, S. I. 1998. Estimating microclimatic elements of a fully developed paddy rice canopy based on standard weather data. *Korean. J. Meter.* 34: 216-221.

세균벼알마름병 예측모형과 국가농작물병해충관리시스템 적용

이 용 환

초 록

Burkholderia glumae 에 의해 발생하는 세균벼알마름병은 전 세계적으로 발생하면서 이삭의 벼알에 감염되어 수량의 중요한 감소요인이 되고 있는 병이다. *B. glumae* 에 의한 유묘기의 증상은 잎집에 갈색의 수침상의 약한 괴사 증상을 포함한다. 감염된 벼알은 쪼그라들면서 담록색이 되고 나중에는 벼알 정단부까지 지저분한 황색이 되면서 매우 건조해 진다. 심하게 감염될 경우 심대한 수량 감소의 원인이 된다. 벼 식물체에서의 세균 집단 동태에 관한 선행 연구에서는 벼 잎집에 집단으로 정착되어 있는 병원균이 초기 감염에 매우 중요한 역할을 한다는 것을 보여주었다. 한국에서 세균벼알마름병은 기상조건에 따라 매 해마다 매우 다르게 발생하였다. 현재 아직까지 저항성 품종은 보고되지 않았다. 이 병을 방제하기 위한 주요한 전략은 출수기 전후에 1회 또는 2회 화학약제를 살포하는 것이다. 하지만, 기상이 병 발생에 충분한 조건이 되지 못한 경우에도 벼 재배자가 농약을 살포하는 경우가 자주 발생한다. 따라서 본 연구는 (1) 세균벼알마름병의 급속한 진전에 관여하는 환경 적합도의 양적 측정 기준을 설정하고, (2) 벼 출수기간 동안에 화학적 방제 여부를 결정할 수 있는 기상 조건의 적합도에 기반한 예측모델을 개발하여, (3) 세균벼알마름병 예

측 모델을 농촌진흥청의 국가농작물병해충관리시스템에 적용하는 것이다. 병 예측 모델을 ‘BGRcast’로 명명하였고, 이 모형은 세균벼알마름병의 대발생에 미치는 매일 매일의 환경 적합도를 결정하고 이에 따라 세균벼알마름병 발생 위험도를 예측할 수 있다. 전남 나주의 시험포장에서 1998-2004년과 2010년에 수집된 모든 자료를 이용하여 모델을 개발하고 모형을 검증하였다. 본 연구에서 우리는 포장에서의 *B. gluamae* 의 밀도 증식과 세균이 이삭감염에 미치는 환경조건의 적합성을 측정할 수 있는 환경 적합도를 제안하였다. 병 예측모형에서는 하루의 환경적합도(C_i,)를 일 최저온도와 평균상대습도를 활용하여 계산하였다. 세균벼알마름병 발병에 미치는 환경 적합도를 분석하기 위해 벼의 생육 단계를 고려하여 세균벼알마름병의 역학적인 발달단계를 생존단계, 전염원 증식단계, 감염단계의 3개의 발병 단계로 설정하였다. 일일 C_i의 평균값으로 전염원 증식단계(C_{inc}), 감염단계(C_{inf})를 계산하였다. C_{inf}를 이용해서 세균벼알마름병의 연차간 변이를 58-87%를 설명할 수 있었는데, 이는 환경적합도가 세균벼알마름병 발생을 예측하는데 이용할 수 있다는 것을 의미한다. 병 예측모델은 세균벼알마름병의 실제 발병을 71.4%의 확률과 47.6%의 오탐지율로 정확하게 예측할 수 있었다. 방제기준을 C_{inc} =0.3과 C_{inf} =0.5를 적용하여 출수직전과 직후에 살균제 살포여부를 결정할 경우 관행 방제 프로그램의 효과를 향상시키는데 유용하다는 것을 확인하였다. 이러한 결과를 통해 일일 적합도 모델이 출수직전과 직후에 방제의사결정을 지원할 수 있는 병 예측모형으로 벼 재배자에게 실질적으로 도움을 줄 수 있다는

것을 확인하였다. NCPMS는 농작물에 대한 전 국가적인 식물병과 해충의 관리 시스템이다. NCPMS는 병해충에 대한 예찰, 예측, 진단의 세가지 시스템으로 구성되었다. 현재, 세균벼알마름병 모형을 탑재하여 *Burkholderia glumae*에 의해 현저한 수량감소가 예상될 때만 벼 재배자가 약제살포를 결정할 수 있도록 서비스하고 있다. 예측정보는 문자를 통해 매일 오전 7시에 자동으로 등록된 사용자에게 서비스되고 있다. 시스템을 등록한 회원 수는 2011년에 1,136명에서 2014년에 4,013명으로 사용자가 매년 증가하고 있다.

주요어 : BGRcast, 화학적 방제, 환경적합도, 국가농작물병해충관리시스템, 세균벼알마름병, 기상에 따른 식물병 예측 모델, 웹기반 예측 시스템